AL.2:1986-729

MAY 09 1980

Information Series No. 67
October 1974

TDA-RCA Capsule Pipeline Project

Capsule Pipeline System Analysis
Part 1
Capsule Pipeline R & D Requirements

edited by
Erik J. Jensen

contributors
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Alberta
RESEARCH

DDN 1005104

TDA-RCA CAPSULE PIPELINE PROJECT

CAPSULE PIPELINE SYSTEM ANALYSIS

PART I

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PREFACE

Transportation costs constitute a significant portion of the total cost of marketing bulk and anticipated large-volume manufactured commodities produced in Alberta. The work on capsule pipelining at the Research Council of Alberta (RCA) is directed towards developing a solids transportation system which can offer cheaper tariffs to bulk and other commodities (cans, etc.) than the presently existing modes of transportation.

Beginning in 1959, the first several years of research made significant progress towards developing and understanding the principles involved in pipelining solid bodies. Also an appreciation was gained of the type of supporting equipment that would be needed to operate a total capsule pipeline system. In 1967-68 the Solids Pipeline Research and Development Association (SPRDA) sponsored a feasibility study jointly with the Government of Alberta and the Federal Department of Industry. The experimental data were generated by RCA in a 4 inch pipeline loop and outside consultants carried out economic and technical analyses. The general conclusion was that based on the state of technology at that time, capsule pipelining would be an economically viable method of transportation in some instances. In 1971 a three-year Transportation Development Agency (TDA) sponsored program was launched with the objective of defining as closely as possible the effect of all of the related parameters on the hydrodynamics of a capsule pipeline system and to produce reliable design equations relating to commercially sized pipe. This study has led to the development of methods for calculating pressure gradients in capsule pipelines. The results were reported in a three-volume project report (RCA Information Series No. 63).

The System Analysis was undertaken as a TDA-RCA cost-shared program towards the end of this hydrodynamic study to evaluate the state of technology for the entire capsule transportation system and to provide, as a tool, a computer model which could be used for preliminary economic evaluation of potential applications for capsule transportation. These detailed objectives were defined in the application submitted to the Federal Treasury Board which in part, reads:

The Transportation Development Agency is sponsoring a three-year research project in capsule pipeline technology, which is scheduled for completion at the end of fiscal year 1973-74. It has successfully addressed itself to experimental and analytical work on instrumented pipelines of various sizes, with the object of furthering the understanding of the hydrodynamics of moving commodities in capsule form through pipelines. As a result, more reliable judgements of the economics involved, and realistic assessment of the suitability to Canadian applications of capsule pipelines may now be made.

At the conclusion of this project, it will be important to be able to assess the viability of a capsule pipeline system with sufficient confidence to justify committing capital investment for a commercial operation. This proposal concerns the studies necessary for this assessment which consists of two parts: one which will qualify, and the second, quantify the factors involved.

Part I, will identify all major physical components of a system, the state-of-the-art of each and the R & D time and expense necessary to attain operational viability. It will assign priorities to R & D work required and produce a critical path diagram for the same.

Part II, will establish a computer simulation model to provide a total economic evaluation of any potential application before development work is commissioned. It will identify all the parameters and variables peculiar to capsule pipelining and reduce them to economic terms. The model will, thus, be designed to optimize systems under consideration and will make it possible to assess the potential of capsule pipelining in more realistic terms than has been possible to date. It will be an invaluable tool for economic and technical trade-off analyses and permit comparisons with other transport modes.

The information produced by simulation models and application studies is needed to provide the necessary information for industry and potential users to assess the viability of solids pipelining using the capsule mode. It will also increase the chances that a successful application evolves from the research expended to date. Close liaison on the work will be maintained with in-house TDA studies in this field and will be overseen by the Capsule Pipeline Technical Review Committee which is chaired by TDA and has members from industry. The results of the analyses together with data from appropriate site-specific application studies undertaken using the techno-economic computer simulation model will be fully documented in a report to TDA.

The final agreement signed between the TDA and the RCA stipulates the scope of the analysis as follows:

Part I: Capsule Pipeline R & D Requirements

1. Describe all major component areas and subdivisions thereof, then assess the state-of-the-art in each area.
2. Determine the R & D required in each area in terms of technological development and innovation.
3. Determine the time and money needed to carry out the necessary R & D and assign priorities to R & D work required.
4. Produce a critical path diagram for the required R & D work for different end uses:
   (a) assuming a fixed date of completion for all work;
   (b) assuming that the necessary R & D is carried out in a sequential order of importance permitting decision on further funding as each step progresses.

Part II: Developing Capsule Pipeline Techno-Economic Simulation Model

1. Identify all parameters and variables in total system (enhancing existing macro-technical model developed by TDA).
2. Determine relationship of each variable with all others in system.
3. Construct flow diagram and identify logic.
4. Develop and debug computer simulation program.
5. Demonstrate utility of model through simulation of typical problem solutions.
6. Collect available data for candidate applications preparatory to undertaking site-specific studies to compare with other modes.

The study therefore fills two separate and distinct needs:

- to provide a summary of the areas in which technological experience is available and a basis for estimating additional development expenditures which are required;
- to provide a means for generating preliminary estimates of the capital requirements and operating costs of specific transportation proposals.

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PART I

CAPSULE PIPELINE R & D REQUIREMENTS

INTRODUCTION

The major objective of the studies of capsule pipelining has been to define the hydrodynamics to permit prediction of pipeline pressure gradients. Equally important, however, in evaluating capsule pipelining as a transport mode are the hardware components of the system. Chapter 1 considers the state of technology and additional R & D work required for each of the components of a capsule pipeline:

Capsule Preparation
Capsule Properties
Pipe and Installation
Injection Facilities
Pipeline Pumps, Booster Stations and Bypass Systems
Retrieval Facilities
Instrumentation and Control
Hydrodynamics

The treatment of hydrodynamics given here is brief because this topic has been the subject of a separate study and has been reported as noted elsewhere. Chapter 2 contains estimates of the costs involved in the additional R & D work required while Chapter 3 details four possible development schemes and sample time schedules for each.

CHAPTER 1

System Components - Status & Requirements

1.0 Introduction

This chapter considers the requirements of the pipeline components in detail and surveys the pertinent information that is available, both from laboratory and larger scale experiments connected with the pipeline project and from applicable work in other fields. It also indicates the work required in the various areas.

Pertinent literature references have been included at the end of the chapter and, because of their large number, they are classified as:

I. Publications from the Research Council of Alberta.
II. Patents held by the Research Council of Alberta.
III. Relevant publications from other groups.
IV. Relevant patents held by other groups.
V. Reports on capsule pipelining.

Additional information required to bring capsule pipelining to the stage where it can be applied commercially requires two types of information:

- Technical information on component design and operation.
- Detailed cost information on the components of the pipeline system.

The outline of required additional work which is included here as the basis for consideration (in Chapter 2) of the time and funds needed, is based only upon the technical information required, the implicit assumption being that cost information is required for every item and does not need to be stated explicitly.

It is hardly possible to discuss capsule pipeline technology in its entirety without including specific commodity details (I - 24, 25; III - 2; V - 1, 2). Some components such as bypass terminals and pumping stations and in part, retrieval systems, are relatively independent of the commodity but others such as capsule preparation and material recovery are very dependent on the commodity. In the following, the most general approach possible has been followed with specific commodity details included where necessary.

1.1 Capsule Preparation

Capsules have, on the basis of their hydrodynamic characteristics, been classified as rigid, semi-rigid and paste slugs in previous literature (1 - 22, 25, 29). From the viewpoint of manufacturing technology, however, capsules may more conveniently be classified as (A) Filled, (B) Cast, and (C) Compressed. This latter classification will be used in this analysis.

In order to be suitable for pipeline transportation, capsules must meet the following conditions:

1. They must be transportable in the pipeline at acceptable pressure gradients - the hydrodynamic condition.
2. They must be sturdy enough to withstand pipeline transportation in long 'trains' - the mechanical condition.
3. They must not react with the carrier liquid - the chemical condition.
4. They must be producible at a rate sufficient to supply the pipeline (and suitable for equally rapid commodity recovery) - the manufacturing condition.
5. The transported material must be recoverable in a usable form at a reasonable cost - the recovery condition.

There are many contributing factors to this overview of the requirements. The hydrodynamic condition encompasses the buoyed density of the capsule as well as its shape and surface characteristics, along with the liquid viscosity. The mechanical condition includes the resistance of the capsule to pressure in the pipeline, to pressure surges caused by rapid valve operation, to impact with other capsules, to squashing or crushing by the following train of capsules and to abrasion with, or by, the pipe. It also includes the capsules resistance to damage during transportation outside the pipeline. The chemical condition includes not only inter-action between capsule and the carrier liquid but also between container and transported material if filled containers are used. The manufacturing condition requires that capsule production, retrieval and material recovery proceed at a sufficiently high rate to transport the required amount of material. The recovery condition includes the form of the recovered material as well as the economic

recovery of material from filled capsules and the recycling or alternate use of the container.

In the context of these capsule design requirements, the different types of capsules can now be considered.

A. Filled Capsules

Filled capsules comprise the entire range of capsules made with hollow containers which are filled with the material to be transported. These containers can have rigid or flexible walls and, to a great extent, their properties are known and the options can be evaluated without physical testing. Other optional factors entering into the choice of fillable containers are recycling (return and reuse) of the containers or its disposal as scrap, for alternate uses or for processing. These will likely be cylindrical type capsules as hollow spherical capsules, while they could be made, would be more expensive and difficult to utilize.

a) - Rigid containers. From an application point of view, rigid containers are the most versatile since the container can be used to carry nearly any solids small enough physically to be enclosed in the container which, in turn, can be up to ~90% of the diameter of the pipe. Density can be adjusted by the degree of filling, or, if unbalancing due to the movement of the cargo is a problem, by mixing low density particles or spheres with the cargo. If the cargo does not interact with the carrier liquid and capsule density is not a problem, the capsule can be 'open' or vented to the pipe which would permit lighter constructior of the capsule since it would not have to withstand pipeline pressure. Potential container materials are noted in Table 1 along with their pertinent physical properties.

Table 1

Rigid Capsule Materials

Material	Density lb/ft.^{3}	Impact Strength ft.lb/in.	Compressive Strength lb/in.^{2}
Steel	491	90	60000
Aluminum	168	0.5-15	12000
Fibreglass	125	1.5-16	25000
Polyvinyl chloride	84	0.4-20	10000
Polyethylene	59	0.5-16	3000

The manufacture of cylindrical capsules comprises the formation of the cylindrical shell and provision of end closures. Design of capsules from any of the materials noted above can be readily carried out based upon projected pipeline pressures (accounting for pressure peaking in the pipeline) and the known properties of the capsule material. With recycled containers, provision of collars or special surfaces for hydrodynamic reasons should be feasible as the added expense will be spread over more transported material; however, for once-through capsules, such sophistication may not be economically possible. Resistance of the capsules to impact may be more difficult to define as the impact velocities and forces encountered during pipeline transport have not yet been determined. Steel capsules will be subject to corrosion while the plastic capsules will absorb oil to some extent. Filling containers at the rate required for pipelining is not a problem as such technology is well established in the food processing, chemical and petroleum industries. For recyclable containers, however, design of a tight closure that will be sturdy, rapidly closed and still readily opened at the downstream terminus is an area for investigation.

The early descriptive papers dealing with capsule pipeline possibilities have assumed rigid containers could be utilized for transporting chemicals, grain (I - 1, 4, 5, 12, 14, 18, 21) and possibly potash (I - 17, 21).

The basic capsule patents described a rigid fillable capsule with one removable end as one alternative (II - 1) although the patents do not define the commodities which might be carried. In the SPRDA study (V - 2), the capsule fabrication consultants considered rigid fillable capsules for transporting iron ore and potash in a Canadian situation and detailed the design of equipment to accomplish this (V - 2, 3). The latter study concluded, however, that the necessity of returning fillable containers from the delivery point to the charging terminal caused the system to be uneconomic for the commodities and the transport situation considered. There have been a number of possible solutions to the economic problem created by returning containers, ranging from design of nesting containers that would give a higher packing 'density' of containers for return shipment by conventional road or rail transport through use of 'dual purpose' containers that could be disposed of independently of the transported commodity at the delivery terminal (i.e. lengths of plastic or aluminum tubing or pipe that could be sold for direct application when retrieved and cleaned) to use of materials that could be reconstituted at the downstream terminal and sold for other uses. The latter would include plastic pipe segments that could be chopped for reuse or metal pipe that could be remelted. The capsule pipeline would be charged with the original capsule fabrication and reconstitution but would recover the bulk of the cost for container-forming material.

Additional work required:

1. Container utilization - the alternatives to returning containers for reuse should be considered both from technological (i.e. constraints on diameter of pipe and on market volume, feasibility of reconstitution or alternate market) and economic points of view.
2. Container strength - the required pressure and impact resistance of containers transported in trains must be determined. This could also entail capsule design work to minimize stresses (e.g. end design of capsules has been found to have little effect on capsule velocities or pressure gradients but could have a major effect on the stress loading under operating conditions - flat or concave ends may create a 'cushion' of liquid which shields the capsule from high impact loads).

3. Closure design - as noted earlier, a container closure is required that can be sealed rapidly and tightly but removed rapidly at the downstream or delivery terminus.
4. Container logistics - container handling, loading and unloading equipment should be considered in detail for the scale of commodity transport required.

b) - Flexible containers. The flexible container is the closest analog to the oil bubble which led to the concept of capsule pipelining originally and differs from a rigid capsule in being somewhat less adaptable to different cargos since density is set by the bulk density of the cargo and the capsule shape tends to be set by the shape of the cargo. This is not a problem if finely divided material is being transported but precludes its use for large segments of material if these cannot be packed into a circular cross-section at a reasonable density. Partial filling is not an option for control of density with flexible walls but addition of lighter particles, previously mentioned with rigid capsules, can be used. There are a number of film materials that could be used for flexible wall capsule formation,and fabrication should not be a problem as sealing techniques have been quite well developed in the packaging industry. Pipeline pressure would not normally affect flexible wall capsule transportation provided the cargo has no sharp edges that can pierce the film and the cargo does not pack. The sturdiness of flexible wall capsules to wear in the pipeline and rupture through impact or compression from the following train is an open question. Closures for most of the common film materials such as polyethylene or vinyls could be through heat sealing as this gives a strong, solid seal. If it were desirable to provide a specific end shape or to reuse the container, a 'mixed' capsule consisting of a rigid closure with a flexible body might be used. This would require development work on closure design and on the junction of the film body to the rigid closure. The actual cargo charging process should present no problem as it is not beyond present industrial capability.

Flexible wall capsules have been considered for grains (I - 5, 12, 14, 18, 21) and for potash (I - 17, 21), in the latter case with the plastic film either enclosing potash crystals or simply protecting a potash 'ingot' from contamination. There have been a few trials made with wheat enclosed in polyethylene film and these showed rapid deterioration of the film due to piercing by the grain. In the SPRDA Study (V - 2.3) the capsule fabrication consultants proposed a flexible wall capsule for sulfur transport and this, as with the potash case noted above, can involve either enclosure of granular material in a flexible wall capsule or prevention of interaction between the cargo and the carrier liquid.

In most flexible capsule uses envisaged, the film would be recovered as scrap for reworking at the delivery terminal. This is dependent, however, on the additives used for film extrusion and the formulation used not being deleterious to further processing.

Additional work required:

Development work required is essentially the same as noted for rigid capsules:

1. Capsule material disposal.
2. Container strength.
3. Closure design.
4. Container logistics.

c) - Comparison of rigid and flexible containers. It is difficult to compare the two capsule types in the absence of more complete information on capsule strength and strength requirements for the capsule transport system. But it is possible to compare the amounts of material required to form the capsules if some assumptions are made about wall thicknesses and film thicknesses used. One such comparison is shown in Table 2.

TABLE 2

Capsules Containing Crystallized Potash*

Rigid Containers	Density lb/ft^3	Wall Thickness in.	Permissible** Cargo lb.	% Vol.
Polyethylene	59	1.00	58.43	100
Polyvinyl chloride	84	.75	56.21	80
Fibreglass	125	.75	41.61	59
Aluminum	168	.50	41.66	53
Steel	491	.25	21.30	22
Flexible Wall Containers				
Polyethylene		.010	85.6	
Polyvinyl chloride		.008	85.6	

* Assumed $7\frac{1}{2}$ inch outside diameter, 3 feet long capsules for an 8 inch pipeline

** Based on maximum capsule specific gravity of 1.5, the vol. % refers to proportion of volume within capsule which can be used under the density restriction which limits capsule weight to 86.15 lb.

B. Cast Capsules

Cast capsules as a class includes all capsules formed by solidifying liquids or recrystallizing particulate solids to form rigid cylinders or spheres without a structural shell or retaining skin. The dividing line between some types of cast capsules and some types of compressed capsules is tenuous but the formation of cast capsules does not require pressure although it may take place at elevated pressures. Currently, the list of commodities considered for cast capsules includes sulfur and iron solidified from the molten state, crude oil frozen in liquefied natural gas and potash crystals agglomerated with small additions of water. Cast capsules may be protected from the carrier liquid by enclosing in a plastic skin and,while this will not contribute greatly to the

integrity of the capsule, it may prevent the solid from becoming dispersed in the carrier liquid if breakup occurs.

Cast capsules come into consideration when the raw material is produced in a form suitable for casting, and would be considered when casting would be a less expensive alternative than filled containers because the costs involved in providing and recycling the container are avoided. On the other hand, casting involves forming each capsule individually in a mold of some sort and keeping it in the mold until cooling or setting permits the capsule to be removed from the mold to complete its solidification. This means that a facility producing cast capsules would be large.

Considerations entering into design of cast capsule systems would be: solid density, volume change on solidification, thermal conductivity, heat of fusion or hydration, mechanical properties of cast billet and chemical reaction with carrier liquid.

In the early papers on capsule pipelining, iron and sulfur were considered the likely candidates for cast capsules (I - 5, 8, 11, 12, 14) with the possible application of foamed sulfur to decrease the density also noted (I - 5, 8). The possibility of recrystallizing potash through the addition of small amounts of water developed later (I - 17) and the use of liquefied natural gas to transport capsules of oil is a more recent proposal. (I - 29, 32, 34; II - 9).

Experimentally, experience with cast capsule fabrication has been limited to tests with sulfur spheres (I - 8, 11) which were made to test the 'ageing' characteristics of the capsules. For sulfur this is important because of the change from amorphous to crystalline structure accompanied by a marked decrease in strength (III - 1, 3, 4). The tests showed good strength initially with a decrease in compressive strength after about 24 hrs. to about one quarter of the original value. The spheres showed a "cored" structure. Addition of a small amount of arsenic slowed the ageing process. In the spherical capsule fabrication tests, molten sulfur was poured into aluminum or plaster molds and allowed to cool to room temperature before removing the spheres. Compressive strengths were measured with a standard compression testing machine using flat heads while impact tests were made by dropping spheres on to a concrete floor. The decrease in volume on solidification of sulfur generally caused formation of voids within the spheres.

The influence of the state of solid sulfur on its mechanical properties has been studied (III - 1, 3, 4) and some methods of controlling the properties attempted (III - 6; IV - 4) to improve the slurry transportation characteristics. An indication of the magnitude of changes in properties with the state of sulfur is given in Table 3 where the tensile strength is listed for the three sulfur allotropes and for two samples of plasticized sulfur prepared at a relatively low temperature (130°C). In general, the strength is proportional to the proportion of amorphous sulfur present and decreases with additions of plasticizer. Plasticized sulfur samples have greater strength if prepared at lower temperatures. It has not yet been possible, however, to suppress the transition to crystalline sulfur sufficiently through plasticizer addition to retain the high, amorphous sulfur strength for the extended periods required for pipeline transport.

The most important question with cast capsules is their fabrication. Economics would likely mitigate against specifically melting a commodity to form cast capsules because of the energy requirement. The rate of cooling and its effect on formation of a thick enough skin to free the mold for reuse is another consideration which is well understood in the iron industry (e.g. iron billets are removed from the mold with liquid cores) but has not been considered for sulfur, potash or other commodities.

Additional work required:

1. Cast capsule formation: The machines required to continuously produce cast capsules at the rates required for pipeline transportation must be designed.
2. Capsule strength: The required impact resistance of capsules in pipeline transport of trains of capsules should be determined. This should be checked against the strength and resilience of the cast commodities.
3. As earlier tests have shown that solution of sulfur in oil is too high, the possibility of a protective film should be studied.
4. Resistance of sulfur capsules to abrasion under pipeline conditions should be studied, along with the friction characteristics.
5. The extent to which density can be controlled by using foamed sulfur should be studied as well as the integrity of foamed sulfur cylinders or spheres. The uniformity of the solid capsule would be of major interest.

TABLE 3

Sulfur Properties

State	Tensile Strength (III - 3) psi	Density lb/ft.^{3}
Monoclinic	60	122
Orthorhombic	43-49	129
Amorphous	100-600*	120
Plasticized - 3% ethylene disulfide (130°C)	272	
- 3% styrene monomer (130°C)	266	

* depends on content, degree of polymerization and distribution of amorphous sulfur.

C. Compressed Capsules

In the classification of compressed capsules are included all capsules extruded or formed by presses to increase their density by improving the packing of the particles or breaking down an open cellular structure. In the case of particulate material, it may be necessary to add some liquid as a binder whereas with cellular material a binder is often present naturally.

Compressed capsules have been proposed for low cost commodities which will form coherent shapes when compressed - to date, coal, sulfur and garbage (I - 8, 10, 11, 12, 15, 16, 18, 20, 21, 28, 29; III - 5, 7) and fabrication experience comprises coal pasted with water and compressed by extrusion through a cylindrical die, so-called coal paste slugs (II - 2, 4). Extrusion through large diameter dies at fairly high velocities seems to be within the reach of machinery designers for materials which will flow, although it does present problems for non-homogeneous materials such as garbage. As examples of the 'state of the art' can be cited the extrusion of plastic bar, pipe and other shapes and the extrusion of sawdust-binder blends for fire-place logs. If extrusion formed capsules are to be used, a continuous bar will be made which can be

cut by the techniques developed for steel plant or plastics extrusion plant use. Other compressed capsules can be generated by briquetting presses or rolls and by more conventional piston compression. Interestingly, the latter type of equipment is currently used to make garbage 'bales' in a disposal system used by American Hoist in St. Paul, Minnesota, although the 'bales' are 3 ft. X 3 ft. X 4 ft. or 36 ft.^{3}, somewhat larger than most pipelines would consider. Similar equipment could be used for cylindrical capsules with redesigned rams and feeding system.

The critical factor in paste slugs is the stability of the paste in the carrier liquid. It is necessary that the pasting liquid be virtually immiscible in the carrier liquid and that the pasting liquid wets the transported solid preferentially to the carrier liquid so that the paste is not unstable. On this basis it has been proposed that sulfur particles pasted with oil could be transported with a water carrier (I - 8). Although self-supporting coal paste slugs could be made for a considerable range of water contents in the paste, pipeline tests indicated a much more restricted useful range, with dry slugs fragmenting and wet slugs expanding or changing shape in the line or breaking up (I - 15, 20). Tests made of the angle of repose of paste capsules in plastic pipe showed a similar variation in behavior with water content. The larger slugs tested in the SPRDA study were individually formed and vibrated to obtain good air removal (V - 2.10). These showed a marked influence of vibration on the fluidity of coal-water mixtures and indicated that higher solids contents could readily be obtained by proper treatment (I - 24; V - 2.10). The few extrusion tests made also attained these higher densities. Some preliminary tests were made in an attempt to adapt the parallel plate viscometer for evaluation of coal water pastes for paste capsule fabrication but these were inconclusive.

Since air voids are included, the density of compressed capsules is a function of the manufacturing process as well as of the densities of solid and liquid components. The hydrodynamic studies have indicated that density is a major factor determining pressure gradients (V - 2.10, 3) and that adjustment of density towards neutral buoyancy can be very desirable. If the density is to be limited, however, it is not sufficient to simply compress to lower pressures since cohesion may be lost. It may be necessary to maintain maximum compression and introduce lower density solids to

decrease the capsule density. In the case of the coal paste slugs, a solid of specific gravity 1.4 and a liquid of S.G. = 1 were used to make paste slugs with density 1.25, while in the case of the St. Paul garbage compression, the bulk density is increased from 6-10 lb/ft.^{3} to 65 lb/ft.^{3}.

It should be noted that although compressed capsules are classified on the basis of their method of manufacture, they may be quite different in their behavior in the pipeline, ranging from dry capsules which behave like rigid capsules to 'moist' paste slugs which may behave somewhat like flexible wall capsules although they tend to expand and compress depending on flow conditions (1 - 15).

Additional work required:

1. The required impact studies on capsule trains to determine the necessary strength of individual capsules should be carried out.
2. The qualifications of each of the capsule materials should be evaluated and compared with the requirements from (1). This may entail tests to consider the effects of particle size, binder content, etc.
3. Design of an extruder which will permit extrusion of coal paste through a large diameter die (i.e. eight inch) at a high rate of speed.
4. Adaptation of the American Hoist waste compactor scheme being used in St. Paul to cylindrical geometry required for capsule fabrication.

1.2 Capsule Properties

In addition to the fabrication considerations noted above, there are a number of capsule properties which influence their movement and which can be considered as characteristic of the capsule rather than of the specific commodity or manufacturing method. These characteristics are:

Density
Diameter (or capsule/pipe diameter ratio)
Length (or length-diameter ratio)
Surface Properties
Shape

The first three of these were taken as independent variables in the hydrodynamic studies noted later and some of the options available for adjusting capsule density have already been mentioned in connection with specific methods of capsule fabrication. The largest capsule shape effect is undoubtedly that between spherical and cylindrical capsules. The choice between cylindrical and spherical capsules has been considered in a number of studies (I - 5, 9, 18, 24; V - 2.10, 3) and the density limit above which spherical capsules would be considered preferable is dependent on the commodity value and the cost distribution between transportation and capsule fabrication. The initial evaluations have been based strictly on pressure gradient consideration, however, and not on a complete economic evaluation such as the model given in Part II will permit. At any rate, in this section the shape effects to be considered are the variations of the basic cylindrical shape. The surface effects, too, relate to cylindrical capsules.

The influence of capsule surface was noted early in the laboratory work (I - 7, 19) during the single capsule tests with plastic and aluminum capsules of the same density in a plastic pipe. The surface effect was also observed in tests made in the SPRDA study (V - 2.10) with steel and plastic capsules in a copper pipe. These tests were exploratory and not detailed but they did show a marked effect of the surface finish of the capsule, the smoother capsules showing only about one-half of the pressure gradient of the steel capsules over the velocity range studied. In the TDA-RCA project, more detailed tests have been made of the effect of capsule surface and the behavior systematized through study of the friction of different capsules in a pipe in 'pulling' tests (V - 3). This surface effect involves both the coefficients of friction of the capsule and pipe materials and the surface roughnesses. (I - 33). There is also a time effect involved since the capsule movement relative to the pipe can alter the surfaces of the capsule and/or the pipe to make them smoother or, in some cases, rougher.

The effect of capsule shape on the transport of capsules in a pipeline was also considered early in the laboratory program (I - 6, 7). The shape of the capsule ends was found to have only a minor effect on the velocity in single capsule movement (I - 6, 7, 13, 14) and has not been studied further. The installation of collars or runners, however, was found to have a marked influence on both velocity and pressure gradient of capsules (I - 26; II - 7; V - 2.10, 3) with the collars located on the forward half of the cylinder

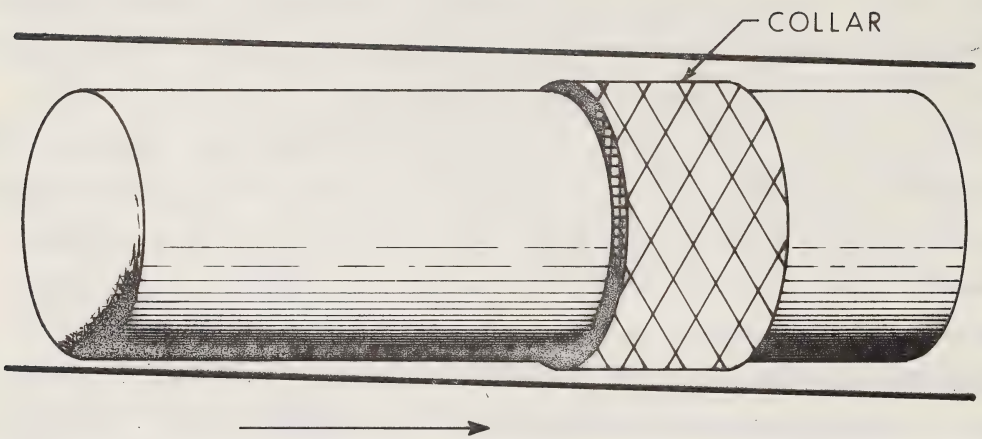
having the greatest beneficial influence. The location and size of the collar has been optimized to some extent (I - 26) and its influence explained through the dual advantages of increasing the average clearance between capsule and pipe wall and changing the flow around the capsule to generate a lift force (Figure 1).

Considering the mechanics of capsule fabrication, production of a particular surface finish does not appear to be a major problem with rigid filled capsules, as a wide variety of surface treatments can be applied to metal objects - ranging from disposable sleeves of plastic to films deposited by spraying or other means. In the 10 inch pipeline used in the TDA-RCA project, a layer of plastic tape has been used (V - 3) to modify the surface of steel capsules. In the case of compressed or cast capsules, it may be desirable to provide a plastic or other film cover that will tend to maintain capsule fragments together should breakage occur. Such a skin can also serve as protection between the capsule and the carrier fluid if contact is not desirable. In the case of flexible-wall filled capsules, the capsule skin would tend to take the contour of the cargo which would probably create "large-scale" roughness superimposed on a smooth skin - a condition which has not been considered experimentally to date. The surface of paste capsules is an inherent characteristic of the paste composition and capsule preparation. It has not been possible experimentally to define the influence of roughness on paste slug behavior - although this presumably would appear as a particle size effect.

The installation of collars on cylindrical capsules is pictured in Figure 1 without detailing location or dimensions (II - 7). In the laboratory lines, collars were installed by a variety of methods - tape, heat shrunk plastic, or soldered metal (I - 24, 26; II - 7) while the field tests used heat shrunk plastic collars with mixed success (V - 2.10) and tape (V - 3).

On an industrial scale, the method of collar installation will depend on the type of capsule being considered. For rigid fillable containers there would not appear to be a fabrication problem as metal containers can be fitted with metal collars secured by welding, heat shrinking or other fastening means, or heat shrunk plastic collars can be fitted, the only problem being to avoid roughness which will abrade the pipe and increase

Figure 1



BANDED CAPSULE

friction. On rigid plastic containers, plastic collars can be heat shrunk, 'welded' or attached with adhesive. It is also possible that plastic containers could be molded complete with one end and the collar, leaving only the filling closure seam as a sealing problem.

It seems unlikely that collars would be used with flexible wall containers as the reduction in pressure gradient would be marginal, the large scale roughness noted earlier providing a similar effect to runners. If it should be necessary, however, flexible plastic strips attached to the 'skin' by 'welding' or adhesive would prove satisfactory.

Cast capsules would normally be cast with an integral collar. The only obvious difficulties being a more complicated mold and a more abrasive situation for the collar which would be subject to spalling. At present, insufficient information is available on the mechanical properties of cast commodities to evaluate this problem. If cast capsules are to be coated, it may be feasible to attach a collar to the film - i.e. multilayer plastic strips.

In the case of compressed capsules, the mechanism of forming will dictate the means or possibility of installing collars. For rigid compressed capsules, collars can be pressed integrally with the capsule with, however, the same reservation that the collar will be subject to more abrasive conditions than the remainder of the capsule surface. As with cast capsules, however, if a plastic film is to be applied to the capsule for contamination or surface reasons, the collar may be attachable to this film. In the case of flexible paste capsules, of course, collars are not possible.

Additional work required:

As far as capsule surface and capsule shape are concerned, more complete evaluation is not meaningful without detailed knowledge of the specific commodity and application since the economics of fabrication are strongly commodity dependent. No new technology is required to install collars on any of the capsule types amenable to collar application but better information should be developed on the costs of fabrication so that the economic comparison of energy saving with additional fabrication expense can be made.

The additional wear on the collar, particularly with cast or compressed capsules should be defined. For surface effects, more complete characterization of the surface would permit more exact prediction of behavior in capsule movement.

1.3 Pipe and Installation

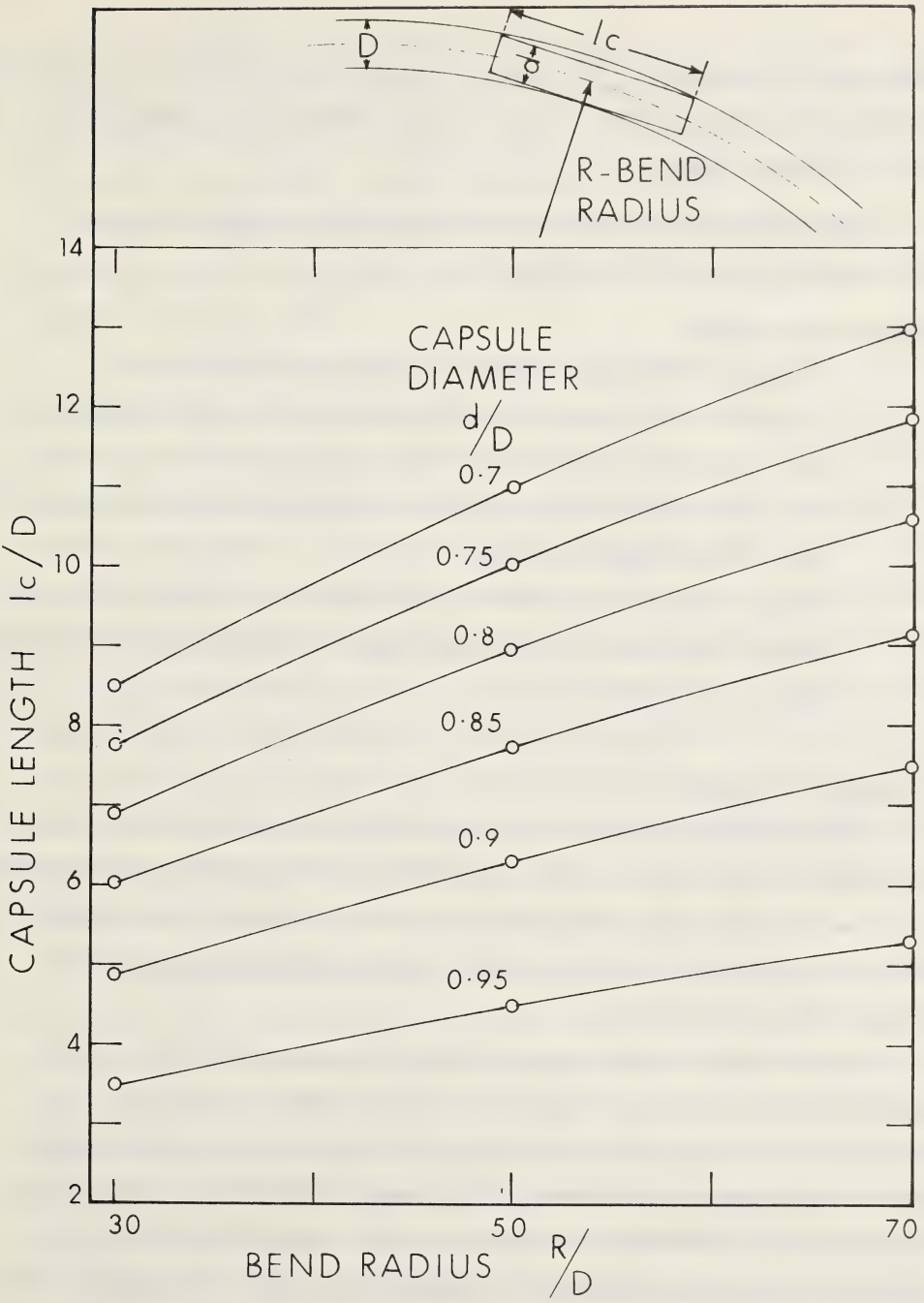
While the material requirements for pipe to transport capsules are not extraordinary as compared with conventional liquid pipelining, there are some special requirements. In particular, care must be taken to ensure that there are no obstructions in the pipe such as welding icicles or flattened bends. While these requirements are of great importance to capsule pipelines, they are within the capability of current technology. It is possible that capsule pipelines in certain applications, specifically where steel containers are used, may be subject to fatigue failure and this consideration should be reflected in the steel specified.

Another desirable requirement which has been indicated by the laboratory experiments is a smooth pipe surface, which shows up in decreased pumping costs and hence decreased operating costs. While installation of plastic and other linings in pipelines is now established technology, most applications have been in natural gas lines to decrease pressure drop (hence increasing the capacity of existing pipelines). No work has been done on the installation of lining in pipes to withstand capsule movement along the pipe, so some development work would be required prior to commercial use.

The addition of small quantities of a polymeric material to the carrier liquid should, in the light of experience with liquid lines, increase the lubricating characteristics of the liquid and allow a lower frictional resistance between the capsule and the pipe wall. However, experiments in small diameter pipelines have not indicated any beneficial effects.

Another condition on pipe installation for capsule pipeline use is the minimum bend radius which can accommodate a capsule of given length and diameter. This situation is shown in Figure 2 with the corresponding graph indicating possible capsule lengths for simple cylindrical capsules. Changes in capsule shape may, of course, modify this relationship. There has not been any work done on bend abrasion in capsule pipelining although, at sufficiently high velocities, the centrifugal force on capsules

Figure 2



BEND RADIUS RESTRICTION ON CAPSULE LENGTH

in a bend may be considerable. This type of investigation should be done on a specific application basis, however, since it will be strongly dependent on capsule and pipe materials and capsule design.

Capsule pipelines will also have grade limitations but these are pressure gradient-imposed and not intrinsic limitations.

Additional work required:

1. Evaluation of friction in different capsule-pipe combinations.
2. Evaluation of the potential fatigue damage due to capsule movement and due to pressure surges caused by rapid valve operation.
3. Evaluation of the shearing stress which must be withstood by the lining bond in lined capsule pipelines.
4. Abrasion tests on pipe bends in capsule pipelines for a variety of capsule shapes (possibly using loaded steel capsules at maximum cylindrical capsule density as a guide).

1.4 Injection Facilities

The injection facilities must accept capsules from capsule fabrication facilities at whatever pressure they are generated and release them into the pipeline at pumping pressures. This can be accomplished by a lock arrangement, by continuous extrusion where it is possible to charge directly from the extruder into the pipeline or by the recently developed rotary bypass valve.

The lock type injector is very versatile and applies equally well to single capsule injection (e.g. the familiar scraper trap in conventional pipelines) or to injection of trains of capsules, the choice of size (i.e. number of units injected per cycle) being determined by the logistics of capsule fabrication to provide good mating between the fabrication and injection cycles. The different barrels of the injector would be charged sequentially either from the capsule fabricator with conveyors or from separate capsule fabricators. Whichever method is used, the capsules would have to be moved into the barrel mechanically or hydraulically.

Continuous injection of capsules into a pipeline will require a multiple barrel injector connected to the capsule fabrication equipment, in the most general case,

through a manifold arrangement with fluid diverter (or mechanical diverter) switching. Alternately, each barrel can be provided with a capsule fabricator so that each 'string' is essentially independent. Of course, if extrusion could be carried out at the velocity of capsules in the pipeline, a single injector could be used.

The vane bypass device will be considered in detail in the section on capsule bypassing; however, for injection use it functions as a multiple lock system with single capsule capacity per lock.

One of the critical factors in the design of an injection facility is the acceleration time or the time to raise the velocity of the contents of an injection 'barrel' to pipeline velocity since this determines the maximum linefill attainable. A second factor which also has an effect on the maximum linefill attainable is the speed of valve operation. These have not been problems in the laboratory lines because capsule trains were batched through the pipeline and only locally high linefills were required and because small valves can be operated with electromagnets and give nearly instantaneous operation. The mechanics of closing or opening a large diameter full-flow valve rapidly are certain to be more difficult and create the associated problem of pressure surges, commonly encountered as 'hammer' in conventional liquid pipeline systems. Some consideration has been given to programmed or controlled opening and closing of valves to avoid pressure surges; however, the effect of such staged operation on attainable linefill has not been considered.

In the experimental facilities in the laboratory, a variety of injectors was used, those for the rigid capsules being based on the 'scraper trap' design (I-6) while those for paste capsules depended on a variety of other designs (I-15, 20) to transmit the paste capsule from the forming mold to a holding barrel until a series of capsules were generated which could be injected as a train. The one different design was a multi-barrel, multi-position rotating cylinder in which the paste capsules were formed in one position and the barrel then rotated until the capsule was introduced directly into the pipeline. A drain was provided at a subsequent position where the oil in the barrel was blown out with compressed air so that the barrel was empty for the next capsule forming step. In the field pipeline facilities, capsules have been introduced

individually through injection 'locks' (V-2.10, 3). The consultants in the SPRDA study considering injection facilities planned their system around a series of parallel, multiple capsule injection chambers using full-flow, full-port ball valves and fluid diverters.

A number of designs of mechanical diverters have been used in the laboratory pipelines (see Figure 3), most being based on the 'swinging pipe' principle where one end swivels and the other is swung between the two outlets. This method interrupts the flow for the period of time that the pipe is being switched, a consequence which was not serious with the small laboratory lines but which certainly could be with commercial scale installations which would have higher operating pressures and longer transfer time. Another design of mechanical diverter has been produced commercially - the so-called spoon diverter which can be turned to align the outlet with either branch of the 'Y'. These designs may be adaptable to more than two outlet streams.

Another concept which may be applicable to trains of capsules in a pipeline is the fluid diverter shown in Figure 4 (II - 6) which is a boundary layer control device which injects liquid on one branch of a Y causing the capsules to move preferentially along the injection branch.

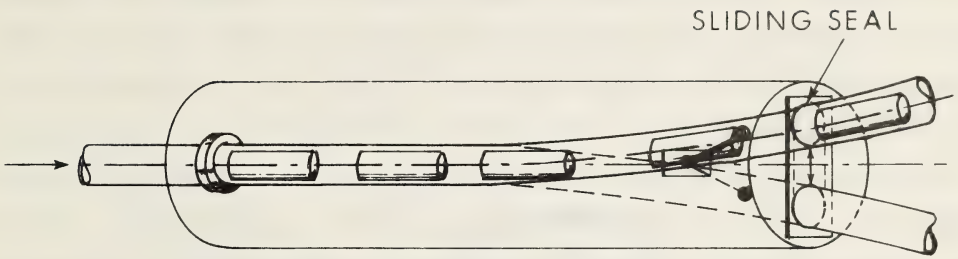
Additional work required:

1. Detailed scheduling of an injection facility based upon available components (i.e. valves, diverter) to determine how high linear linefill can be realistically considered.
2. Consideration of mechanical diverter design and development of an operable prototype suitable for commercial use.
3. Development of the fluid diverter to a commercial scale operation and definition of its operating characteristics.

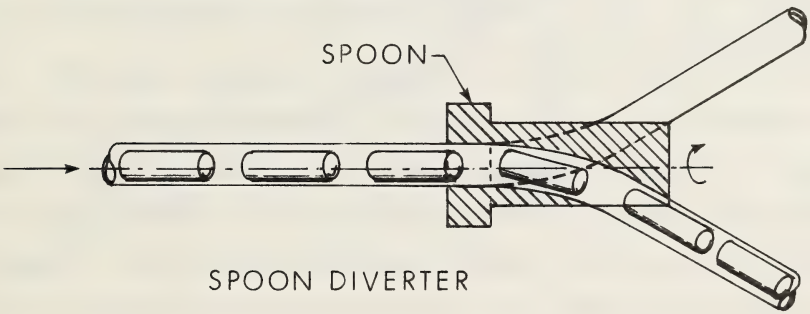
1.5 Pipeline Pumps, Booster Stations and Bypass Systems

One of the components of a capsule pipeline system which is unique is the repressuring or booster station. This presents special problems in capsule pipelining because the large capsules must either be passed through the pump or bypassed around it in order to maintain continuous commodity movement.

Figure 3



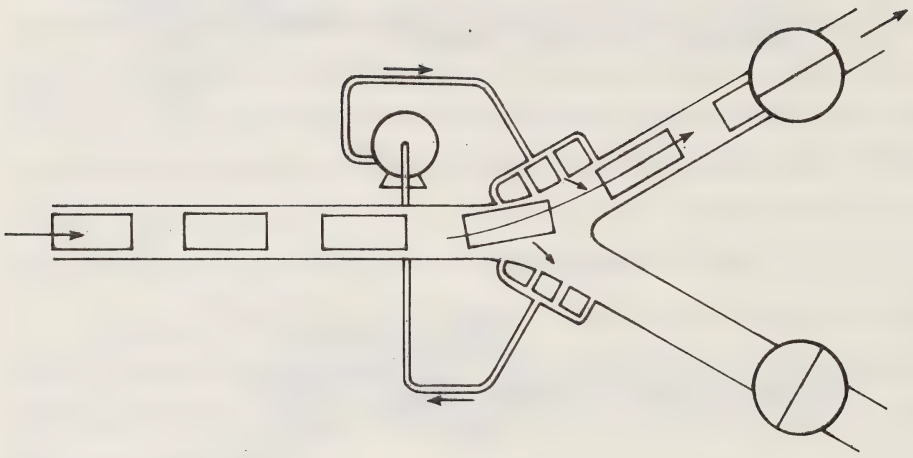
SWINGING PIPE DIVERTER



SPOON DIVERTER

MECHANICAL DIVERTERS

Figure 4



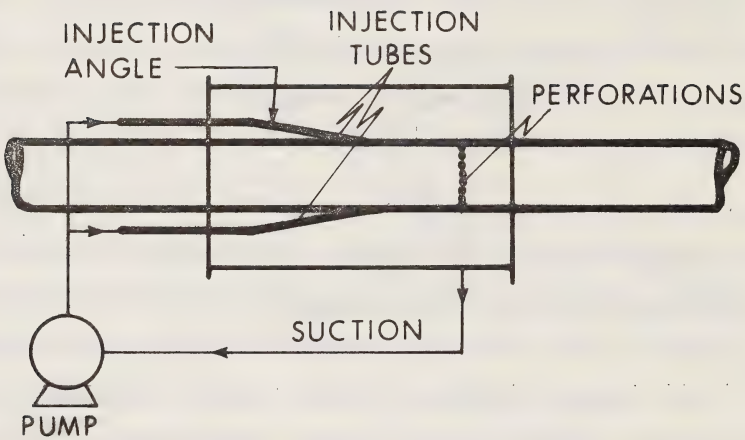
FLUID DIVERTER

A bypass system for a capsule pipeline must accept capsules as they arrive at low pressure from the pumping station upstream, transport them across the pressure differential from the low pressure side to the high pressure side and discharge them into the pipeline downstream of the bypass. The capsules must be passed with a minimum of mechanical stress to avoid disintegration and at a sufficiently rapid rate to provide the required flow of capsules. Two general classes of bypass have been considered - the lock type which collects the capsules at the discharge end of the pipeline in a series of parallel barrels and then closes off the upstream contact and opens the downstream to flow the capsules into the system (II - 3; III - 2; IV - 1, 2, 3) and the in-line pump which accepts capsules and repressures the flow. Two types of in-line pump systems have been considered, one, the vortex pump, (II - 5), depending only on the momentum of liquid jets directed downstream and entering tangentially to create a vortex to withstand pressure, and the other being based on the rotary vane valve noted earlier (II - 8) with a conventional pump connected in parallel.

The acceleration type pump suffers from backflow which limits the pumping power which can be transmitted to the capsules. One model of this pump is shown in Figure 5 while Figure 6 shows the influence of angle of injection on internal circulation for a range of water injection rates while the effect of injection tube diameter is shown in Figure 7. These indicate that higher injection velocities and shallower angles of injection lead to lower internal circulation rates. While no scale up work has been done on the vortex pump, it should be scaleable on the basis of the Euler number, viscosity having little influence provided turbulent flow is maintained. The efficiencies obtained are not considered sufficiently high to make this pump attractive in comparison to alternative pumping designs.

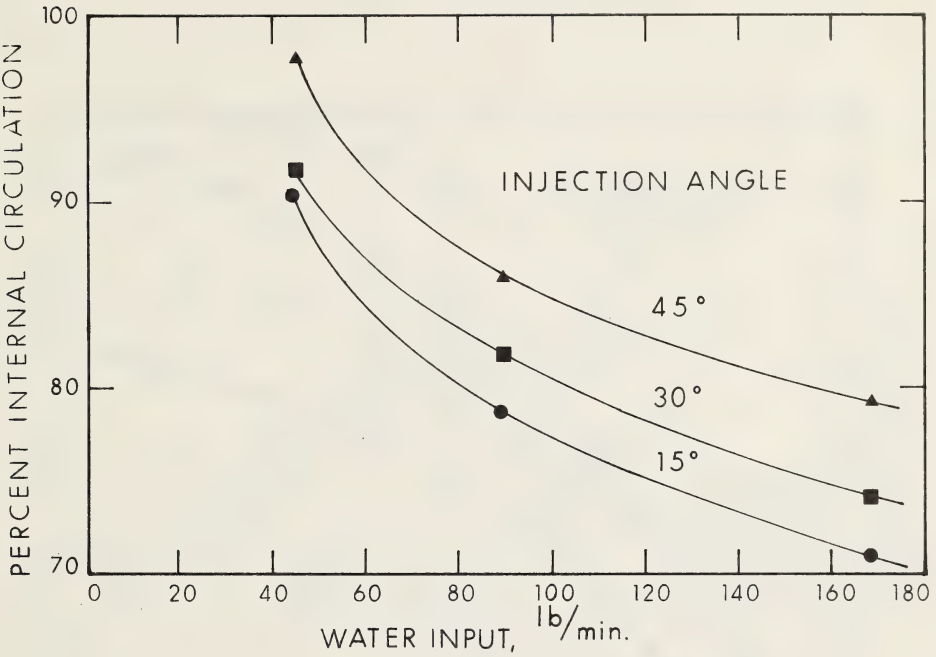
The second in-line pump system involves the combination of an in-line vane bypass with a conventional pump. Two modifications of this concept are shown in Figures 8 and 9 (II - 8), the former being for spherical capsules and the latter for cylindrical capsules. In normal operation the vane bypass would accept capsules as they appeared and pass them through to the exit without stopping them or even slowing them down. This is desirable to decrease the energy required to accelerate capsules when they are released on the high pressure side. Liquid is withdrawn on the upstream

Figure 5



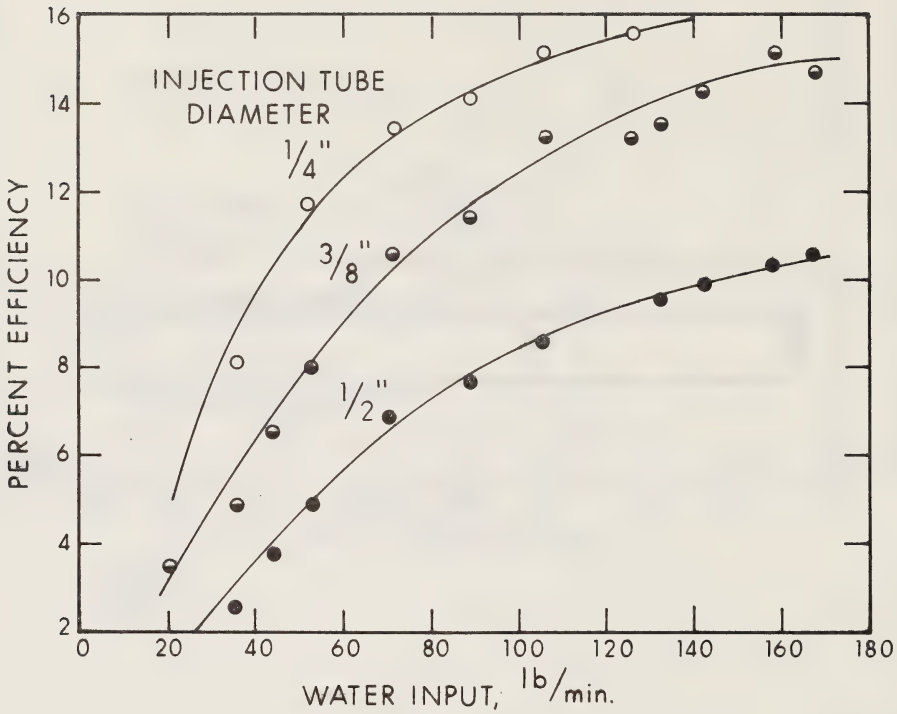
VORTEX PUMP

Figure 6



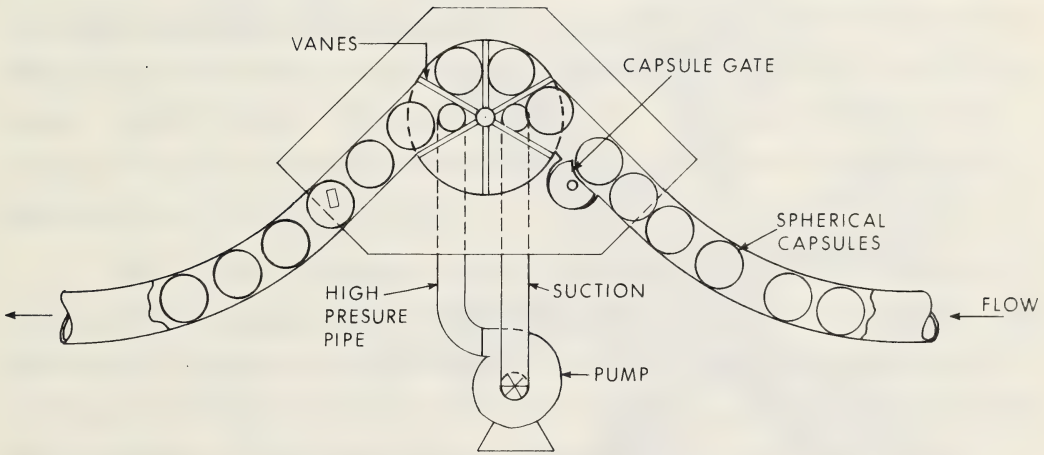
VORTEX PUMP - INFLUENCE OF INJECTION ANGLE

Figure 7



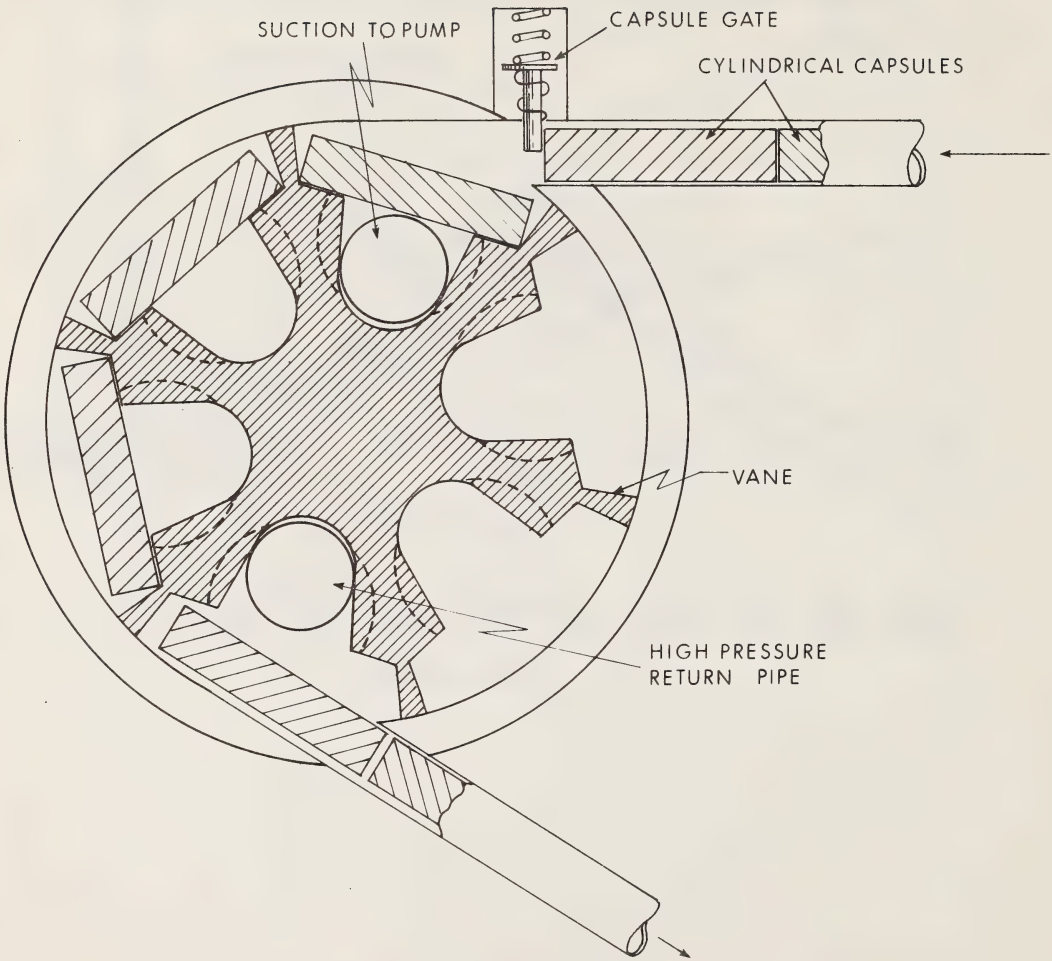
VORTEX PUMP - INFLUENCE OF INJECTION TUBE DIAMETER

Figure 8



VANE BYPASS DEVICE - SPHERICAL CAPSULES

Figure 9



VANE BYPASS DEVICE - CYLINDRICAL CAPSULES

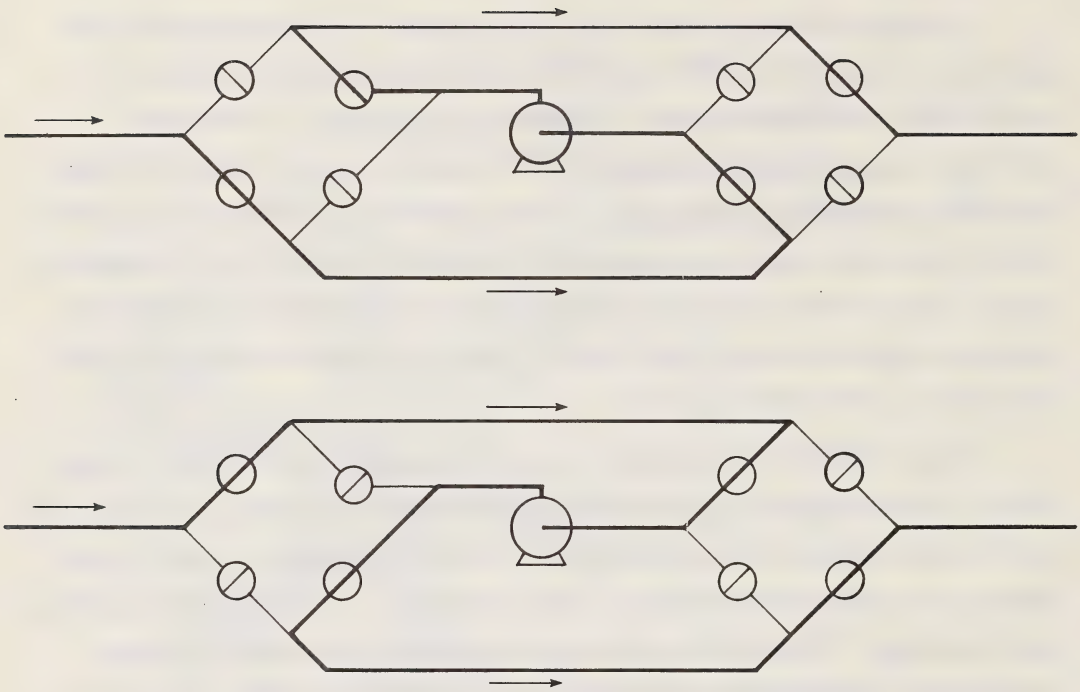
side of the valve and reinjected downstream, thereby moving the capsule on its course again. The two major design problems in the vane bypass device are the seal around the vane which separates the high and low pressure sides of the vane and the casing which must withstand full pipeline pressure and will be quite large physically for large capsules.

A number of lock-type systems have been proposed, all doing essentially the same thing - accepting capsules until the barrel is filled and then switching to fill another barrel while the first barrel is emptied into the pipeline. As with the vane bypass system, the choice of pump is determined by the pressure drop and liquid throughput requirements and there are no special requirements for the capsule pipeline. The lock system does require some specialized components, however, for the bypassing system - notably full-flow full-bore valves, a diverter system and instrumentation to manage the logistics of capsule handling for all systems and special liquid withdrawal sections for use with paste slug systems.

Figure 10 shows the bypass arrangement conceptually for a two barrel system. In essence, the pump suction is connected to the downstream end of the barrel being filled and the pump discharge to the upstream end of the barrel discharging capsules to the pipeline. By cycling between the two barrels, essentially continuous capsule discharge can be achieved. The mechanics of this cycling determines the linefill achieved. It is essential, of course, that the bypass system be capable of ejecting capsules and liquid at the same rate at which they enter, despite the fact that capsules must come to a complete stop between input and output cycles. The balance between liquid and capsule flow rates must be preserved in spite of deceleration and acceleration effects.

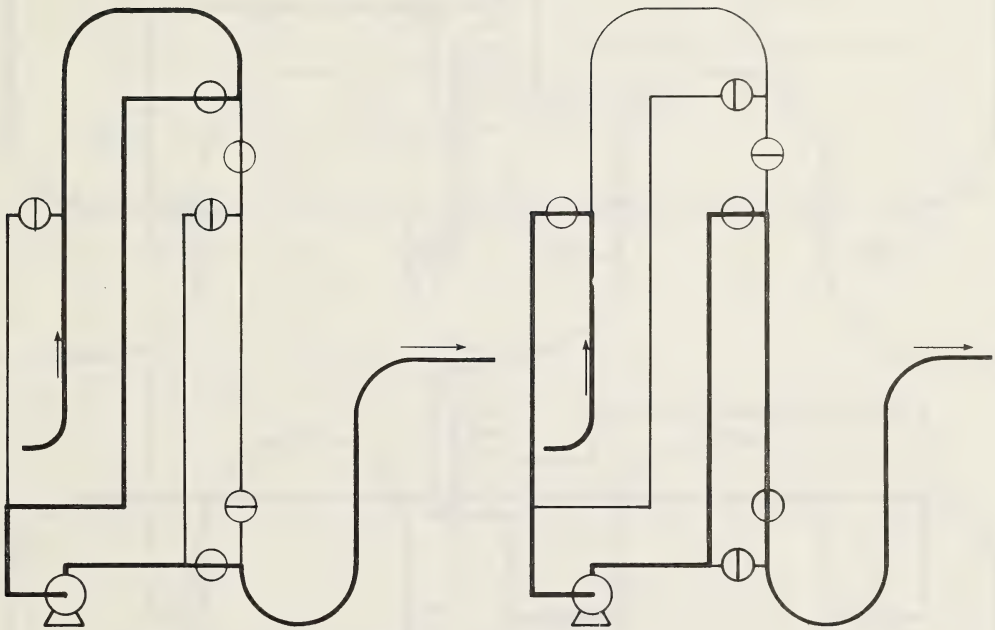
Some of the variants used in the laboratory for bypassing are shown in Figures 11 through 13 (II - 3). Figure 11 shows an early single barrel design which used gravity to carry the capsules through the upstream line valve. This was used only for single capsules although it could be modified to accept short trains. In this design the reduced velocity of capsules during the free fall limits the attainable linefill. Liquid withdrawal was accomplished with a perforated section of pipe designed so that liquid could be removed from paste capsule pipelines without breaking the capsule. In operation, valve switching was initiated by photocell sensors placed upstream of the line valves which detected the passing

Figure 10



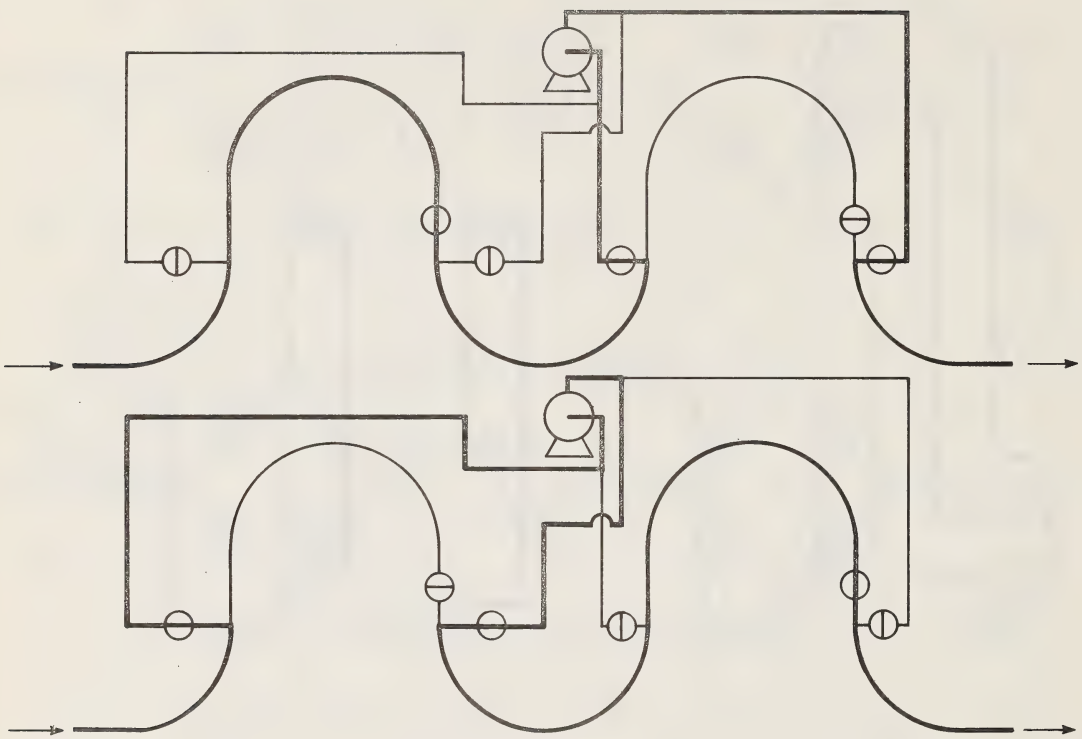
BYPASS SCHEMATIC

Figure 11



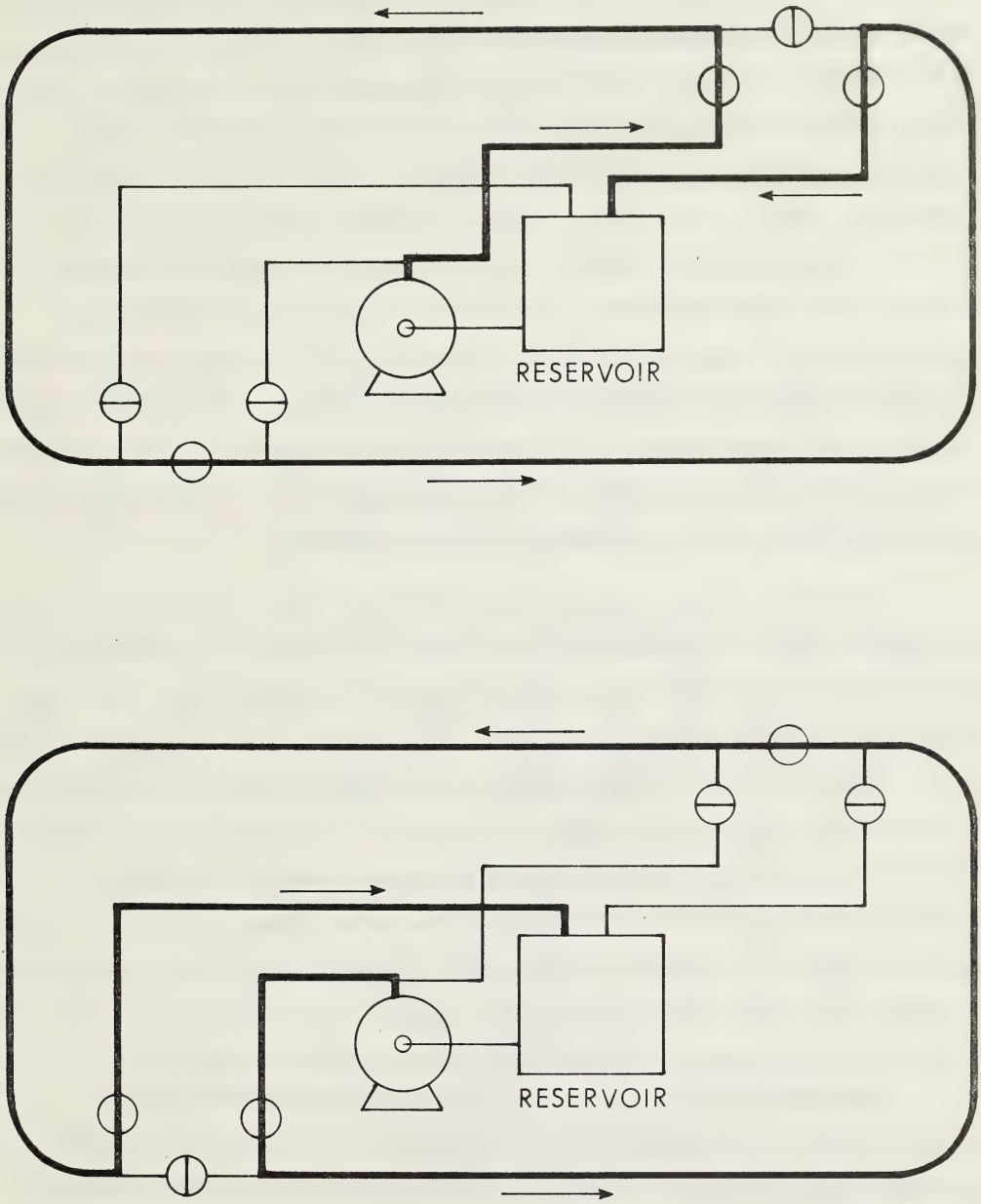
GRAVITY ASSISTED BYPASS - LABORATORY

Figure 12



"POWERED" BYPASS - LABORATORY

Figure 13



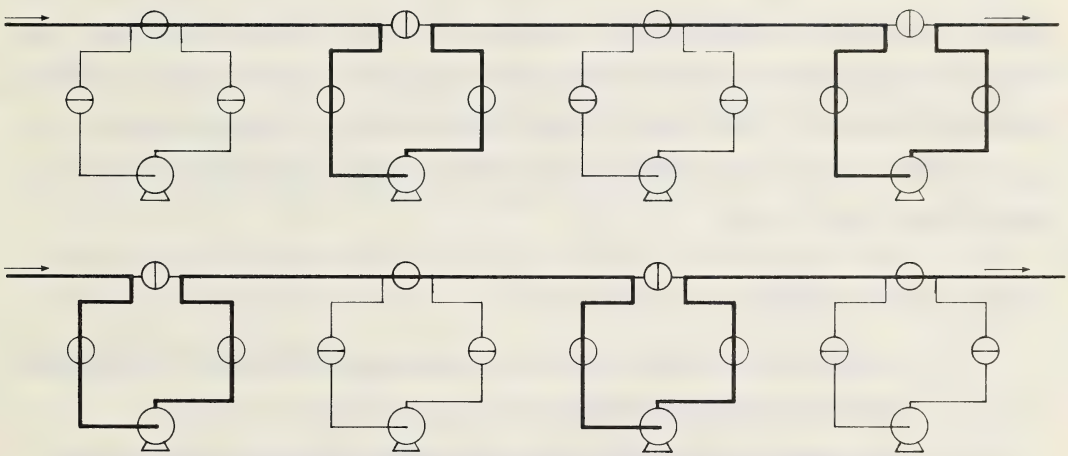
LOOP BYPASS - LABORATORY

capsule and operated the valves downstream. A modification of this same idea for single capsule systems which does not depend on gravity is shown in Figure 12. One disadvantage of these designs is the dead liquid between the pump suction and reinjection locations which necessitates acceleration of the liquid to line velocity from zero velocity. This amount of dead liquid can be minimized, however, as shown in the loop design of Figure 13 (I - 20), or, better still, in the long distance modification of Figure 14 (II - 3). These essentially 'leap-frog' the train through the pipeline by pumping alternately from successive stations. All of these single barrel or single chamber modifications have a maximum linear linefill less than 50% because liquid alone has to be pumped to remove the capsules from the barrel on discharge. Use of a second parallel chamber permits higher linefills to be reached as indicated earlier. In turn, multiple barrel installations can reach higher linefills than double barrel ones but require more complicated instrumentation to accomplish proper sequencing.

The lock-type bypass systems require full-flow full-port line valves that allow the capsules to pass. In the laboratory lines these were solenoid operated sliding valves or ball valves while the field tests used ball valves for the 4 inch loop. The 10 inch shuttle line does have one full-flow, full-port plug valve but this is not used as a line valve. There will not likely be any problem in obtaining any practical size of full-flow, full-port ball or plug valve that might be required for a commercial capsule pipeline but it will be a problem to attain the speed of operation required to operate a system to attain high linefill. Aside from the line valves, there are no special requirements for valves for the capsule pipeline system. Large diameter sliding valves are also available commercially but are designed for vacuum system installations and do not have to withstand the pressure differentials that pipeline operation would require.

Operation of the lock-type bypass systems also requires some means of diverting capsules into different pipes as was discussed in the section on injectors. For steel capsules mechanical diverters could accomplish this but a more intriguing solution and, one that might provide a less severe test of the capsules, is the fluid diverter which utilizes hydraulic forces to direct capsules along one channel or another. All of the mechanical diverters suffer from the same problem. As they all require a gap between capsules to permit the movement of the diverter without jamming. It should be noted that the creation of a gap for diverter operation was not

Figure 14



LONG DISTANCE BYPASS SCHEMATIC

considered earlier in connection with the injection equipment because the capsule fabrication operation immediately upstream will provide adequate spacing between successive capsules to permit operation. As economic considerations will likely dictate operation at as high a fractional linear linefill as possible and as capsules do not travel at exactly the same velocities due to variations in specific gravities, dimensional tolerances and surfaces, this space requirement may become difficult to guarantee after the capsules have travelled some distance in the pipeline. If a gap must be created, the options are to decelerate the trailing capsules or to accelerate the leading capsules and, since the momentum of the trailing capsules may be substantial, there really is no option - the leading capsules must be accelerated relative to the rest of the train. This might be accomplished by either (1) injection of additional carrier liquid circulated from an auxiliary reservoir, (2) decrease in pipe cross-section, or (3) change in grade - the aim being to create an intermediate section in which capsule velocities are higher and hence linear linefill is less.

Additional work required:

1. Consideration of mechanical diverter design and development of an operable prototype for commercial use.
2. Development of the fluid diverter to a commercial scale operation and definition of its operating characteristics.
3. Consideration and evaluation of possible methods of adjusting capsule train movement to permit diverter operation.
4. Development of the rotary vane booster - bypass system to commercial scale.
5. Definition of the limitations of the vortex pump.
6. Development of pump and valve specifications for the different bypass options.
7. Detailed scheduling of a bypass facility based on available components.

1.6 Retrieval Facilities

Retrieval facilities as considered here include the means for removing capsules from the pipeline at the delivery terminus, separating them from the carrier liquid, retrieving the cargo from the capsule if necessary and in some cases, the reconstitution of the cargo. Treatment of the carrier liquid should also be included if necessary.

Very little work has been done on the retrieval of capsules from a capsule pipeline, this being equivalent technology to existing materials handling installations. There are potential problem areas in individual cases due to maintenance of static head in the system if there is a large drop in elevation upstream of the unloading terminus, but this simply requires a multiple barrel recovery system similar to the multiple barrel bypass arrangement with the associated diverters and valving or adaptation of the rotary vane system to 'gate' capsules out of the pipeline. There will be concern about liquid drain-off or possible washing of the capsules if oil is used as carrier fluid or if the carrier fluid contaminates the solid being transported (as with oil in coal-water paste slugs) but the amount of such liquid will be small as shown by laboratory drain tests (I - 15). In practice, such draining could take place from a bank of rollers serving as the interface between pipeline and downstream conveyor system or through a perforated belt conveyor taking the capsules directly from the pipeline as assumed by the consultants in the SPRDA study (V - 2.4). In the case of spheres, it may be desirable to use a 'flight' conveyor so that the spheres are not free to roll. If a moving conveyor is used directly, it will be adjusted to the capsule exit velocity to minimize capsule breakup.

If fillable containers are used, it will be necessary to retrieve the commodity from them unless the containerization is desirable for on-going transportation at the delivery terminus. In the case of rigid containers this will entail either opening the end closure if the capsules are reusable or simply cutting the capsule open if the shell is to be reprocessed. In the case of flexible wall capsules, the cargo would be recovered by cutting the flexible casing and the casing recovered for reprocessing or other disposal. Cast capsules or rigid compressed capsules would not generally require reconstitution chargeable to the pipeline unless they had protective film which required removal. Flexible paste slugs, based on the experience with coal (I - 15), would be easily returned to powder state by removal of a small fraction of the pasting liquid.

Additional work required:

1. Development of workable pipeline-conveyor interface for capsule handling capable of operating at considerable pressures.

2. Development of methods of capsule deceleration including the 'blind alley' (i.e. letting the capsules pass into a closed, liquid filled pipe) and mechanical retarders. This should include definition of the stresses experienced by the capsule.
3. Determination of the liquid retained on capsules during draining.
4. Design of end closures for reusable and non-reusable rigid capsules.
5. Development of commodity retrieval and reconstitution equipment.

1.7 Instrumentation and Control

Instrumentation for capsule pipelining entails:

1. Sensing devices to monitor capsules passing a station, their velocities and the liquid velocity and temperature.
2. Control logic to operate bypass stations to accommodate approaching capsules.
3. Telemetry equipment to permit continuous monitoring of the state of the system from a central control point.
   (a) Number of capsules in a given control section.
   (b) Capsule arrival frequencies at given control points.
   (c) Pressures throughout the system.
   (d) Temperatures throughout the system.
4. Feedback mechanism to cause the system to react to upstream conditions including feedback control of capsule fabrication and injection.
5. If the pipeline is a common carrier, ability to discriminate between different capsules in sensing the above parameters and to operate diverter systems to separate different classes of capsules.
6. Software to permit coordination of the entire system.

While highly instrumented laboratory systems have been used in the pipeline studies (I - 27, 30, 31; V - 2.10, 3), very little instrumentation applicable to field purposes has been developed or demonstrated. However, while instrumentation for capsule pipelines presents some novel applications for existing components, only a few new components are required. Among the latter, the most important is a means of sensing capsules, which will be required for bookkeeping, for automatic scheduling and for valve and diverter action.

There are a number of methods by which capsules can be sensed. They fall into two general categories - those which require a tag on the capsules and those that will sense some characteristic of the capsule. The tagged capsule concept is probably the most versatile since capsule identification could be readily coded into the tag sensing system which would almost certainly be necessary if common carrier operation was contemplated. The tagging mechanism would have to be quite positive, however, and not subject to removal in transit. Radioactive tags could be used if the carrier liquid was opaque or reflective tags for either visible or infrared light. The light dependent methods are subject to failure if the carrier liquid becomes contaminated.

If the tagged capsule system is not used, capsules must be sensed by some inherent characteristic such as interception of a light beam, distortion of a magnetic field, interception of a neutron beam, distortion of an ultrasonic signal, etc. - The optical sensing methods are subject to interference from contamination of the carrier liquid as is neutron interception. These methods might not be as adaptable to common carrier operation of a capsule pipeline as they would not be able to discriminate between capsules unless there is sufficient difference in the property sensed. This would only be significant for the diverting or sorting function, however, as the use for valve operation in bypassing would be equivalent for all capsules.

The other major new requirement of instrumentation is the design of switching systems to minimize pressure surges when using rapid valve operation.

There will undoubtedly be more sophisticated techniques developed once experience with commercial pipelines is obtained. For example, capsule loading could be adjusted on the basis of the surface characteristics of the capsule to produce trains of capsules that would travel at a uniform velocity thereby minimizing capsule interaction.

Instrumentation applications fall into three main categories:

(a) Pipeline operation - pump valve and diverter operation.
(b) System monitoring and control-sensing of upsets or velocity changes and correction of potential problems, feedback to upstream components.
(c) Bookkeeping - inventory of in transit material and material delivered.

Additional instrumentation may be required to detect and locate leaks, blockages or capsule breakup, and to take corrective action. It is also quite possible that shutdown operations will have to be optimized for simple restarting.

Some quality control instrumentation will be required in the capsule fabrication area because of the potential penalties of capsule breakup and also because of the effects of density differences between capsules in a train on train integrity.

Additional work required:

1. Consideration of possible means of capsule sensing and evaluation of these means to select the best sensors for different applications.
2. Software development for pipeline operation.
3. Optimization of valve operation vis a vis pressure surges.
4. Development of leak detection and location devices.
5. Development of capsule integrity monitoring devices.

1.8 Pipeline Hydrodynamics

The bulk of the research in capsule pipelining over the last 15 years has been directed towards an examination of the hydrodynamic factors influencing the amount of energy required to pump capsules through a pipeline. Experimentally, studies have extended from the initial laboratory studies with tubes one inch in diameter or less (1 - 2, 3, 6, 7) through the 4 inch field loop (V - 2.10) to the more sophisticated $\frac{1}{2}$, 1, 2, 4 inch and 10 inch shuttle lines of the TDA study (V - 3). These studies have been directed, for the most part, towards better definition of the fluid mechanics of capsules and have led to the methods of pressure gradient prediction given in the final report of the TDA-RCA Capsule Pipeline Project (V - 3). Alternative approaches to the analysis of capsule hydrodynamics have been provided by Govier and Aziz (III - 8), Singh (III - 9) and Lazarus (III - 10).

As noted in the hydrodynamic study, the capsule pipeline system is complicated by interaction of variables - the physical situation precludes independent adjustment of liquid and capsule velocities. The hydrodynamic study was designed to measure pressure gradients for a variety of different conditions to provide the data bank with enough basic data to evaluate different models of the capsule flow situation. It is not proposed to consider the hydrodynamics in great detail here since this has been the object of another study (V - 3), however, it will be useful to highlight some of the findings of this study, particularly those that have a bearing on the characteristics discussed in this report.

1. Capsule specific gravity - the closer the capsule specific gravity is to that of the carrier liquid, the lower the friction force between the capsule and the pipe (and the lower the pressure gradient).
2. Capsule shape - for dense capsules, use of the spherical shape can decrease pressure gradient by an order of magnitude. Collars installed on the capsule nose also cause a marked decrease in capsule pressure gradients, in some cases.
3. Surface effects - coating of the capsule and/or pipe with a smooth plastic can cause markedly lower pressure gradients.
4. At higher velocities and with more viscous liquid, the liquid pressure gradient is higher but capsules tend to travel closer to the centerline

of the pipe with decreased frictional drag which may give lower overall pressure gradients.

More important, however, than these general observations which serve as guidelines in preliminary designs are the methods of estimating pressure gradients in pipeline flow of cylindrical and spherical capsules.

Briefly stated, the method of predicting cylindrical capsule pressure gradients is based on calculating the pressure drop components due to capsule-pipe friction and liquid flow in the annulus separately and combining them to give a total pressure gradient along the capsule. A number of ways of either obtaining or estimating the component due to capsule-pipe friction have been suggested and the prediction of pressure gradients for most applications is reduced to the problem of estimating this friction component for the capsule and pipe combination to be used.

For spherical capsules the pressure gradient was found to be relatively independent of capsule density and predictable as a function of sphere diameter and liquid pressure gradient. Imperfect spheres whether out-of-round or non homogeneous - required higher pressure gradients while surface roughness also affected the gradients to some extent. As with cylindrical capsules, the problem becomes specification of the system properties - in this case mainly those of the spheres.

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CHAPTER 2

Development Projects Required

2.0 Introduction

The previous chapter considered the 'state of the art' for capsule pipelining and the fund of knowledge that the capsule pipeline designer has to work with, noting also the additional information required. The present chapter preceeds from this base to detail the additional studies needed to develop capsule pipelining and the personnel and funds necessary to carry out this additional work.

Before considering these projections in detail, however, a few words about the basis for them is in order.

a) Test facility - In a number of projects it is necessary to produce prototype components to demonstrate that the designs are suitable for industrial scale application. As it is not reasonable to charge the total cost for such a testing facility against each project, it is proposed that a single testing facility be constructed to serve all. It would be constructed in two stages. The first would be a 4 inch diameter instrumented loop about 3500 ft. long for the initial scale up tests on the more complex components. The second would be a 10 inch diameter instrumented loop about 2000 ft. long to be used for scale up of these components to commercial sizes and the collection of other necessary information on system operation.

b) The manpower requirements and costs of the development work are quite dependent on the procedure adopted and on the intensity of effort. As much as possible, the work has been assumed to proceed at a continuous rate. It could in most cases be accelerated by deploying additional personnel to the project. In the cost estimates, employee costs were based on the following scale:

Professional employees	$20,000/yr
Machinists (skilled tradesmen)	$11,000/yr
Technicians	$ 9,000/yr.

Consultants have not been included as a separate cost item explicitly although in many cases consultants would be required. Overhead charges range from 150% to 250% of salaries depending on the degree of supporting services required.

c) The estimates for testing of prototypes, where necessary, have been separated from the prototype design and construction estimates to permit better evaluation of the significance of the estimates. Cost of prototype production also includes an allowance for installation costs to allow for modification of the test facility and provision of additional equipment required. The $6,000/month charge for testing covers operating costs including salaries for use of one loop of the Test Facility, on the assumption that only one loop is required. If the amount of testing requires operation of both test loops simultaneously, the Test Facility would require more operating employees. The costs and times shown are based on one shift operation five days per week. Obviously the test program could be accelerated by operating additional shifts. No capital cost recovery is included in the operating costs on the assumption that such a facility would be provided by the group funding the research as a service facility.

d) Costs are current as of early 1974.

e) As these are all short term projects, costing assumes no construction of buildings or provision for standard equipment apart from the Test Facility.

f) The cost estimates included here are made without the benefit of detailed knowledge of the respective research and development programs for the components. They have therefore not been made in detail and are subject to considerable variation depending on the specific programs chosen by the groups contracting to do the work.

The proposal to construct two test loops may be challenged on the basis of initial capital cost. The reasoning was, however, that the cost and time required for prototype modification for the rotary valve bypass device, the instrumented capsules and the vortex pump would be much greater if scale up to 10 inch diameter was carried out in one step. This approach also has the advantage that a first industrial installation, for example a garbage transport pipeline, may be feasible based on the model prototype

tests and this installation might then be used for full scale prototype testing, eliminating the need for the second loop.

In the projects listed in this chapter, some rationalization of the testing programs has been assumed. In particular, the abrasion tests, some of the pipe tests and some of the capsule tests could be carried out concurrently with bypass device tests if proper provision for data accumulation is made. This has been noted in the individual project description.

It is not intended that the options suggested here or in the literature (cf. Chapter 1) are the only ones that could be considered. To arrive at cost estimates for development work it was, however, necessary to have a development program in mind. It was assumed that the groups involved in individual projects will not be limited by past experience but would use this only as a base to start from in the development of new methods and equipment.

2.1 Model Prototype Test Facility Loop

This will be the first unit in operation at the test station and it is intended primarily for testing scale up models of the rotary vane valve and developing the additional equipment to permit development of a working bypass device. It will also be used with an instrumented capsule to test the stresses imposed on capsules during capsule transportation, information required to design capsule fabrication methods and also to monitor the effect of bypassing on the stresses experienced by the capsule.

To provide the required testing capability, the test facility would have to be a loop so that the capsule train could be cycled through the pipeline and the pump bypass continuously. It would have to be designed to permit modifications.

As outlined earlier, a 4 inch diameter pipeline loop is considered optimum for this stage of development. To give useful data on capsule interactions (i.e. for the instrumented capsule work) a long line is required so that stable conditions can be attained. This would require a loop about equivalent in size and capability to the SPRDA loop and it would be advantageous to model on this scale the effects of incline and decline between capsules. This would necessitate a loop of 3000 to 4000 ft. - similar to the SPRDA loop.

Capital cost of such a loop complete with incline, decline and horizontal test sections would be about $150,000 and the unit could be operated on a one shift basis by a two man crew plus a supervisor. Operating costs, not including capital charges would be about 50% of salaries, based on experience with the SPRDA line and the TDA-RCA project field station. This presupposes that all charges related to a particular testing program are charged to the program and not to loop operation. On the salary basis used here, operation of the test loop would cost about $2000/month and salaries about $4,000/month, so the rental cost of the facility would be $6,000/month with personnel included.

Design of the facility would require about 3 months, tendering 2 months and construction 3 months. Engineering costs involved in these aspects of the facility are included in the capital cost esimate.

2.2 Full Scale Prototype Test Loop

This facility is intended for the final scale up of the rotary bypass device developed on the model scale and for testing of capsule performance during pipeline operation. There would be very little sharing of equipment between the two test facilities because of the difference in scale and the fact that testing programs may be run simultaneously in the two test facilities.

A second, equally important, purpose of the test facility is to carry out more detailed instrumented capsule tests to define the stresses imposed on capsules and to permit optimization of capsule shape, pipe and capsule surfaces, etc. This would require a horizontal test section and a bend section, necessitating a loop about 2000 feet long and 10 inch in diameter. It would cost about $210,000.

Operating costs for the full scale prototype will be about the same as for the model prototype facility and it is quite feasible that both could be operated simultaneously without additional staff. For the purpose of this estimate, however, they have been assumed to be separate facilities and operated independently.

Rental costs would be $6000/month (exclusive of capital charges) composed of $4000/month salaries and $2000/month operating expenses.

Construction would not be greatly different from the model prototype - 4 months design, 2 months tendering and 5 months construction.

2.3 Proposed Capsule Pipeline Development Projects

CONTAINER UTILIZATION

This is largely a market survey of the possible terminal uses for capsules and should include both the reuse and reprocessing options for all fillable containers. This would entail identification of likely container materials and, for these alternatives, evaluation of:

1. Cost for disposal as waste.
2. Technical and economic evaluation for various direct reuse options i.e. long capsules could be cleaned and sold as pipe, cut into short lengths and used for small containers. The second option would, of necessity, involve evaluation of the market for specific container diameters and materials.
3. Evaluation and costing for various reprocessing options, i.e. the shredding of the container material at the delivery terminus for direct use or re-melting as a raw material. This would likely be a lower value use than option 2 but would not be an added cost as in option 1. Of particular importance here would be possible limitations on reuse caused by initial processing, i.e. deleterious effects of additives or fillers used upstream of the original pipe fabrication.

Scope of Work:

A 'paper' or literature study using literature information available and evaluations from potential users. An engineering consultant has been included.

Personnel required:	Period:
1 Professional	6 months
Cost:	
Staff	$ 10,000
Overhead @ 100%	10,000
Consultant	4,000

CLOSURE DESIGN

This requires complete design from the conceptual stage through to prototype construction and testing. The detailed closure design will depend, of course, on the type of container, the material and the container disposition at the downstream terminus, but it is likely that a common basic design can be used for rigid containers or for a rigid closure for flexible containers. The closure would be tested for tightness and for ease of operation without a pipeline but prototype designs would be tested in the test facility with a train if possible to simulate more closely the stresses likely to be encountered in commercial operation.

Scope of Work:

Engineering from conceptual design through to detailed design, followed by construction and testing of prototypes in static pressure chambers and pipeline facilities.

Personnel required:	Period:
1 Professional	6 months
1 Machinist	3 months
1 Technician	12 months

Cost:	
Staff	$22,000
Overhead @ 200%	44,000
Materials & equipment	3,000
Test facility 1 month @ $6000/mo.	6,000

CAST CAPSULE FORMATION

It is not possible to design a capsule casting system without the design being based upon a specific set of material properties - heat of fusion, thermal conductivity of liquid and solid, etc., and a specific design capacity. In the case being considered, if a firm design objective is not available, the object would be to design prototype casting units for cylinders and spheres that could operate at rates in the estimated commercial range. The use of foaming and other density control measures should be considered also.

An allowance for capsule testing has been included on the assumption that a commodity choice will be possible and that individually cast capsules could be produced for testing. This would be a prerequisite to construction of a commercial scale casting facility.

Scope of Work:

Preliminary engineering design of casting systems for cylindrical and spherical capsules.

Personnel Required:	Period:
2 Professionals	8 months
2 Technicians	6 months

Cost:

Staff	$34,000
Overhead @ 150%	51,000
Materials & Supplies	10,000
Test Facility 2 mos. @ $6000/mo.	12,000

COMPRESSED CAPSULE FORMATION

(a) COMPACTOR

This involves the design of a hydraulic compactor to produce a cylindrical bale. The actual compactor design should be fairly straightforward as units for rectangular bales exist but some ingenuity may be required in modifying the feed equipment. This should be followed by prototype construction and testing.

Scope of Work:

Machine design and construction of a prototype unit for testing in the test facility.

Personnel Required:	Period:
1 Professional	2 months
1 Machinist	6 months

Cost:

Staff	$13,000
Overhead @ 150%	19,500
Materials & Supplies	10,000
Test Facility 2 mos. @ $6000/mo.	12,000

COMPRESSED CAPSULE FORMATION

(b) EXTRUDER

For some commodities, one of the fabrication options is continuous extrusion into the pipeline from a paste to form rigid or paste capsules. Major considerations are the extrusion velocity and the pressure generated in the cylinder which would be the maximum line pressure into which the capsules could be extruded directly. It is believed that extruder design could be made to the specifications for capsule extrusion without additional development testing. The overall extruded capsule installation would have to include feeding and cutting equipment and would be quite commodity sensitive.

Scope of Work:

Design study in conjunction with extruder manufacturers.

Personnel Required:	Period:
2 Professionals	6 months

Cost:

Staff	$20,000
Overhead @ 150%	30,000
Materials & Supplies	2,000

REQUIRED CAPSULE STRENGTH

Capsules in the pipeline are submitted to pressure surges during bypass operation, to compression from the movement of other trailing capsules in a train during deceleration and to shock from impact with other capsules during pipeline operation. As well as studying the pressure force exerted on capsules in a pipeline, this study is intended to study the impact of capsules in normal pipeline operation and the crushing of capsules by the momentum of following capsules and the hydrodynamic forces on a trailing portion of a train. While this could be accomplished in a variety of ways, the estimates here are based on use of instrumented capsules with enclosed data recording equipment and subsequent computer processing of the results. The testing program is assumed to take place in both the 4 inch and 10 inch test loops with initial tests being made in the smaller diameter loop. For contrast, costs are also included (II) for the pilot plant testing of specific commodity capsules for integrity during pipeline operation, which will demonstrate their resistance to impact failure but not crushing failure, since it is not feasible to build a long enough pilot line. Crushing failure should be amenable to determination with standard compression testing equipment, however, based on estimates of the forces involved.

Scope of Work:

Design and construction of instrumented capsules for use in the test facility and use of these to determine the stresses imposed on capsules in pipeline flow.

Personnel Required:	Period:
I. Instrumented Capsule	
1 Professional	30 months
1 Machinist	6 months
2 Technicians	30 months
II. Commodity	
1 Professional	3 months
1 Technicians	3 months

Cost:

I. Instrumented Capsule

Staff	$100,500
Overhead @ 250%	251,000
Materials & Supplies	60,000
Test Facility 10 mos. @ $6000/mo.	60,000

II. Commodity

Staff	$ 7,300
Overhead @ 150%	11,000
Materials & Supplies	5,000
Test Facility 1 month @ $6000/mo.	6,000

CAPSULE STRENGTH

Tests are being made in another study to determine the stresses imposed on capsules in pipeline transport by (i) line pressure, (ii) impact with other capsules, and (iii) crushing from other capsules collectively as a train. This study is intended to develop tests that will permit evaluation of capsules, filled containers or cast capsules, relative to these external stresses and to evolve standards for capsules.

Scope of Work:

Laboratory evaluation of different testing methods and correlation of the results with capsule performance where possible. This would require some testing in the prototype testing facilities.

Personnel Required:	Period:
1 Professional	8 months
1 Technician	6 months

Cost:

Staff	$17,900
Overhead @200%	35,800
Materials & Supplies	8,000
Test Facility 2 months @ $6000/mo.	12,000

CAPSULE SHAPE

It has been established that the end shape of capsules has minimal effect on the hydrodynamics of capsule movement. The study outlined here should verify this and also determine effects of end shape on impact velocity with a view to determining if impact stresses can be lowered by preliminary capsule designs (i.e. liquid cushion). The influence of banding and similar modifications have been studied extensively relative to hydrodynamic effects and do not require further evaluation at this time.

Scope of Work:

The study of the effect of end shape on inter-capsule forces could probably best be made on an instrumented test bench which would yield measurements of the retarding force exerted on a submerged model capsule nose approaching a model tail at constant velocity in carrier liquid. The influence of the overall flow of carrier liquid on this interaction should be negligible. If this method is chosen, a variety of end shapes could be tested.

Following the bench scale work, tests would be carried out in the full scale prototype test facility to confirm the prediction under actual conditions - probably using the instrumented capsules developed in the study on required capsule strength.

Personnel Required:	Period:
1 Professional	18 months
1 Technician	30 months
1 Machinist	9 months

Cost:

Staff	$ 67,000
Overhead @ 200%	134,000
Materials & Supplies	25,000
Test Facility 6 mos. @ $6000/mo.	36,000

SURFACE EVALUATION

The importance of the capsule and pipe surfaces to the movement of capsules has become very apparent during the TDA-RCA project. To date, however, allowance for surface effects has been based upon analogy and no detailed effort has been made to characterize the surfaces to permit correlation of capsule behavior. Development of a general predictive method for capsule pipeline design requires a method to evaluate surfaces that can be fitted into a theory of lubricated solid-solid movement. Such an evaluation would have to account for two effects - the surface roughness (or, more properly, the surface roughnesses of both surfaces), and the nature of the surfaces.

Scope of Work:

This would be a comprehensive study, starting from the proposition that surface effects are very important and continuing through the development to characterize the surfaces experimentally and develop the relationships necessary to predict capsule behavior. The applicability of the relationships developed would be tested in the test facility. These tests would likely be made in conjunction with other testing programs but three months of test facility operation have been charged against this project to allow for extended test programs with other projects designed to generate the data required for specific surface evaluations.

Personnel Required:	Period:
2 Professionals	24 months
2 Technicians	24 months
1 Machinist	24 months

Costs:	
Staff	$138,000
Overhead @ 200%	276,000
Materials & Supplies	100,000
Test facility 3 mos. @ $6000/mo.	18,000

ABRASION RESISTANCE

Both capsules and pipe wall may be subjected to abrasion damage under some conditions of capsule pipelining. Of particular importance is the abrasion occurring in bends because of the greater force exerted between the two solid surfaces. This study is a paper evaluation of the damage potential and includes recommendations of pipe material specifications for capsule pipelines from the point of view of abrasion resistance and design of experiments to be made in the Test Facility.

Scope of Work:

Engineering evaluation of the problem of abrasion in capsule pipelining, both from pipe and capsule points of view, assistance with design of Test Facility abrasion monitoring procedures.

Personnel Required:	Period:
1 Professional	3 months

Costs:

Staff	$5,000
Overhead @ 200%	10,000
Materials & Supplies	2,000

COATING OF CAPSULES

With some capsules which are sufficiently strong structurally to maintain their shape, it will still be necessary to provide a coating to prevent interaction of the capsule material and the carrier liquid. This requirement could be for protection of either the liquid or the capsule solid.

Coatings could be of a variety of materials - polyethylene, polyvinyl chloride, etc. and the particular material chosen may determine the mechanics of coating - spray, dipping or shrink fit film. The coating study should result in recommendations as to the type of film and the method of application for specific applications.

Scope of Work:

Consultant report: the evaluation of different films for use as coating and the evaluation of the different methods of application.

Evaluation of tests carried out on capsules in the Test Facility: while these would not be carried out specifically for the coatings project, but in conjunction with other test programs, one month of facility time has been charged against the coatings work.

Personnel Required:	Period:
1 Professional	6 months
1 Technician	6 months

Costs:	
Staff	$14,500
Overhead @ 200%	29,000
Material	5,000
Test Facility 1 month @ $6000/mo.	6,000

LIQUID RETENTION

There is not too much general work that can be done on liquid retention as it will tend to be specific for the capsule and liquid being considered. For specific capsule-liquid combinations that are being actively considered, draining tests in the laboratory can be used to determine the drain time required in the interface before the capsules are processed further. The liquid retention will be significant economically if the carrier liquid is costly, such as oil, and may have significance technically if the capsule is to be reprocessed or if the retained liquid adversely affects the transported solid. Also included in the study should be the effectiveness of washing carrier liquid from the capsule.

Scope of Work:

Specific commodity - liquid combinations should be investigated in a laboratory study which would require one technician. If work on characterizing capsule surfaces is being carried out, the liquid retention results should be correlated with the surface properties and the liquid characteristics.

Personnel required:	Period:	
1 Professional	1 month	per capsule-liquid pair
1 Technician	3 months	

Costs:

Staff	$4000
Overhead @ 150%	6000
Materials & Supplies	4000

BONDING OF COATINGS

It may be necessary or desirable to bond a coating onto the pipe or onto the capsule (including the installation of collars). Whether the coating is on the capsule or the pipe, the bond will be subjected to shear forces from the movement of the capsules over the surface and, in the case of collars, shear from fluid flow past the capsule. The study will have to estimate the shear stresses either from the flow model or experimentally and compare this with the bond resistance to shear. The analysis here assumes that adequate estimation of the shear stress can be made without experimental determination.

Scope of Work:

Materials testing to determine the resistance of various types of possible coating bonds to shear failures.

Personnel Required:	Period:
1 Professional	5 months
1 Technician	5 months

Cost:	
Staff	$12,000
Overhead @150%	18,000
Materials & Supplies	7,000

COMMODITY RECOVERY

The transportation of capsules after retrieval is considered in the project on Capsule Handling. In addition to handling the capsules, however, it is necessary to consider the equipment required to recover the commodity from the capsule - be it a filled, cast or other type of capsule. This study would involve the full range of possible capsules.

Scope of Work:

A survey of available techniques for material recovery from all types of capsules. Until a specific commodity and capsule has been chosen, the study would be general in scope. The study would coordinate the details generated by the studies on capsule properties, capsule utilization, capsule handling, closures, etc.

Personnel Required:	Period:
1 Professional	8 months

Cost:

Staff	$13,000
Overhead @ 200%	26,000
Materials & Supplies	3,000

PIPE EVALUATION

While the requirements for pipe to be used in capsule pipelining are not stringent, there are some differences from conventional pipeline operation which may influence material selection.

These are:

1. A capsule pipeline may require frequent and rapid changes in flow at bypass station. The consequent frequent change in pressure may cause material fatigue.
2. The frequent passing of capsules over joints may cause additional stresses in the pipe.

Also included is the design of monitoring installations in the Test Facility to monitor the imposed stresses on the pipe.

Scope of Work:

Engineering evaluation of the effects of the particular stresses caused by capsule pipelining on the pipe and its performance and recommended material specifications for the pipe. Assistance with design of pipe evaluation tests for the Test Facility.

Personnel Required:	Period:
1 Professional	4 months

Cost:

Staff	$ 7,000
Overhead @ 200%	14,000
Materials & Supplies	2,000

TRAIN VELOCITY ADJUSTMENT

For proper operation of capsule diverters or of the rotary vane valve, it is necessary to adjust velocities to create gaps between capsules upstream of the diverter or valve. Development of the techniques to accomplish this would have to proceed in parallel with the development of the bypass system or systems. As this would have to be based on prototype installations in a demonstration line, appreciable effort will be required in detailed engineering design and prototype construction, depending upon the system chosen. Examples of possible methods of accomplishing this velocity adjustment are:

1. Injection of additional liquid to accelerate the capsules over a given section, and
2. Use of smaller diameter pipe in one section to accelerate the capsules.

Injection of additional liquid would also entail withdrawal of this liquid - that is, there would be a superimposed liquid circulation over a section of pipe. This would require a storage reservoir for the recirculating liquid as well as a control system to equalize the injection and withdrawal rates.

The alternative of restricting the pipe diameter to accelerate capsules, however, requires a smooth transition between the two pipe sizes. It may not be possible to operate a paste slug pipeline with this type of velocity control because of capsule disintegration.

Scope of Work:

Preliminary engineering evaluation of alternative methods for adjusting capsule velocity in the pipeline followed by detailed design, construction and testing of prototype based on the system which appears preferable. The costs given below are based on development of a single prototype:

Personnel Required:	Period:
1 Professional	2 months
1 Machinist	2 months

Cost:

Staff	$5,200
Overhead @ 200%	10,400
Materials & Supplies	10,000
Test Facility 1 month @ $6000/mo.	6,000

FLUID DIVERTER

The conceptual design of the fluid diverter has been published and a bench scale study made of some of its design and operating characteristics. Additional experimental work is required to establish the relationship between the injection rate and the weight of capsule being controlled prior to construction of an industrial scale prototype.

Scope of Work:

A. Experimental work to establish the energy or momentum relationship of the fluid diverter.

B. Design, construction and testing of an industrial-scale prototype.

Personnel Required:	Period:
A. 1 Professional	6 months
1 Technician	12 months
B. 1 Professional	5 months
1 Machinist	3 months
1 Technician	9 months

Cost:	
A. Staff	$19,000
Overhead @ 200%	38,000
Materials & Supplies	5,000
B. Staff	$18,000
Overhead @ 200%	36,000
Materials & Supplies	12,000
Test Facility 3 months @ $6000/mo.	18,000

MECHANICAL DIVERTER

There have been a number of different designs of swinging pipe diverter used in the laboratory which differ mainly in the design of the downstream or switching connection. An alternative design of mechanical diverter involves use of a rotatable core or spoon to deflect flow to one side of a "Y" connection. These designs of mechanical diverter and any other suitable designs should be considered relative to the following operating characteristics:

1. Speed of operation.
2. Stresses imposed on capsules passing through.
3. Maintenance requirements.
4. Material requirements.
5. Cost.

Scope of Work:

Engineering evaluation in conjunction with diverter manufacturers.

Personnel required:	Period:
1 Professional	2 months

Cost:

Staff	$3,500
Overhead @ 150%	5,000
Materials & Supplies	2,000

BYPASS DEVICE

The vane bypass and booster device has been built and operated for a small laboratory pipeline but requires scale-up to a commercial diameter and pressure. This will require detailed consideration of the effectiveness of the seal formed by the vanes against the housing in preventing leakage from outlet to inlet. This is a similar problem to that faced by the designers of the rotary piston internal combustion engine, although the temperatures for the vane ducts will not be a problem. Casing design to withstand pipeline pressure is a second consideration since the casing will be physically large to handle the capsules for a commercial installation. Construction of two prototypes - one model (4 inch) and one full scale (10 inch) for the Test Facility is foreseen in the estimates below.

In addition to the mechanical design of the vane, consideration of its method of operation in a bypass device must be carried out to develop operating limits. It is intended to include determination of the operating power required for vane operation and the operating velocity of the vane required for maximum linear linefill (i.e. the linear velocity of capsules through the vane must be higher than their velocity in the pipeline in order that the outlet capsule linefill can be controlled).

A parallel investigation is foreseen to consider the adjustment of capsule velocity to match the peripheral velocity of the vane.

Scope of Work:

Design and construction of two prototype units followed by testing in the appropriate test facility.

A. Model prototype.

Personnel required:	Period:
1 Professional	8 months
1 Machinist	3 months

Cost:

Staff	$16,000
Overhead @ 150%	24,000
Materials & Supplies	25,000
Test Facility 2 months @ $6000/mo.	12,000

Note: The above cost estimate is for one cylinder bypass device, including pump and control equipment. A cylinder bypass prototype should cost about 50 to 60 percent more than a sphere bypass because of its larger size.

B. Full Scale Prototype.

Personnel Required:	Period:
2 Professionals	6 months
2 Machinists	8 months

Cost:

Staff	$35,000
Overhead @ 150%	52,500
Materials & Supplies	60,000
Test Facility 5 months @ $6000/mo.	30,000

Note: The above estimate is for one sphere bypass device, including pump and control equipment. The sphere bypass was chosen for the large prototype to speed the program as it is a smaller unit than the equivalent cylinder bypass would be.

VORTEX PUMP

The vortex pump has been studied conceptually and on a small laboratory scale during development but a considerable amount of ingenuity and experience will be required to optimize the design so that a valid comparison can be made with other systems for an industrial scale operation.

Scale of Work:

Research and development work to optimize design parameters followed by design construction and testing of an industrial scale prototype.

Personnel Required:	Period:
A. Laboratory Study.	
1 Professional	18 months
2 Technicians	18 months
1 Machinist	3 months
B. Prototype design and construction.	
2 Professionals	8 months
1 Machinist	9 months
2 Technicians	6 months.

Cost:	
A. Laboratory study	
Staff	$60,000
Overhead @200%	120,000
Materials & Supplies	20,000
B. Prototype design and construction.	
Staff	$44,000
Overhead @ 200%	88,000
Materials & Supplies	50,000
Test Facility 3 months @ $6000/mo.	18,000

CAPSULE DECELERATION

In connection with some capsule pipeline components, notably the multiple chamber bypass, it is necessary to stop a portion of a capsule train. The object of this study is to consider possible ways of accomplishing this with as mechanical retarders, fluid mechanical retarding (closed tube), etc., to evaluate on paper their operating characteristics and to determine their applicability to capsule pipelining. This should also include consideration of the stresses imposed on a capsule by the retarder.

The results will then be checked with one of the test facility pipeline loops.

Scope of Work:

Desk study, followed by experimental verification.

Personnel Required:	Period:
1 Professional	2 months

Cost:

Staff	$3,400
Overhead @ 150%	5,000
Materials & Supplies	2,000
Test Facility 1 month @ $6000/mo.	6,000

CAPSULE HANDLING

In a complete capsule pipeline, capsules must be handled upstream of the injector and downstream of the capsule retrieval units. While such handling is more extensive in the case of filled containers where the container must be filled and sealed at the charging terminal and opened and emptied at the discharge terminal, it is equally important for cast capsules which must be transferred from the casting molds to the injector and from the pipeline terminus to a remitting plant. The technology appears to be available in the material handling industry and, consequently, no extraordinary development costs have been included.

Scope of Work:

Contract design work by materials handling consultants.

Personnel Required:	Period:
2 Professionals	6 months

Cost:

Staff	$20,000
Overhead @ 200%	40,000
Materials & Supplies	5,000

INTERFACE

The delivery terminus of a capsule pipeline may require a closure to 'gate' capsules out of the pipeline under pressure, or it may be possible to simply run them out at atmospheric pressure. The capsules will in both cases have to be separated from the liquid and transferred to the appropriate downstream processing.

Scope of Work:

Evaluation of the potential methods such as mesh conveyor, roller conveyor, etc. of separating liquid from capsules and transporting capsules away from the pipeline. This technology currently exists so desk study preceding commercial design should be sufficient. 'Gating' against a back pressure has not been included here as a separate study as it will be covered by the bypass development study.

Personnel Required:	Period:
1 Professional	8 months

Costs:

Staff	$ 3,000
Overhead @ 200%	6,000
Materials & Supplies	2,000

CAPSULE SENSING

Proper operation of a capsule pipeline system will depend on the ability to monitor the location of capsules in the system and this will require a rapid, reliable method of capsule sensing. In the case of simple transportation, it is necessary only to sense the movement in order to operate valves in the bypass systems while for common carrier operation the sensing function will be needed to sort the capsules into the appropriate streams for delivery.

Scope of Work:

1. An evaluation of the methods (optical, ultrasonic, magnetic, mechanical, radioactive, etc.) that can be used to detect capsules in a pipeline. This study should consider the preferable methods for all of the potential transported material and the relative merits of particular systems. A follow-up laboratory study would be required for particular commodities and detection methods unless the behavior was deemed sufficiently predictable to design directly for industrial scale in the test facility installation.

2. Re-evaluation of the methods of (1) for use in common carrier operation where sorting of the capsules is required and capsules carrying different cargos must be identified. This would require equipping each capsule with an identifiable cargo 'tag' or durable distinctive color.

Personnel Required:	Period:
1. Single Commodity.	
1 Professional	18 months
1 Technician	12 months
2. Common Carrier	
1 Professional	12 months
1 Technician	12 months

Cost:

1. Single Commodity

Staff	$39,000
Overhead @ 200%	78,000
Materials & Supplies	10,000
Test Facility 3 months @ $6,000/mo.	18,000

2. Common Carrier

Staff	$29,000
Overhead @ 200%	58,000
Materials & Supplies	15,000
Test Facility 3 mos. @ $6000/mo.	18,000

INSTRUMENTATION SOFTWARE

This involves, for a specific system, analyzing the components of the pipeline system and committing the logistics of their operation, as well as of interaction with other components, to a control sequence in a process control program. This will have to consider all phases of the operation from raw material feed to the final disposition of the cargo (and possibly of the container). This program must be based on all the information collected and generated during the other segments of the study.

Scope of Work:

Analysis of capsule pipeline system operation and development of computer program for control of the capsule pipeline system.

Personnel Required:	Period:
2 Professionals	4 months

Cost:

Staff	$13,000
Overhead @ 250%	33,000
Materials & Supplies	2,500

DETAILED SCHEDULING

The operating time required by components of a capsule pipeline imposes limitations on the capacity of the line. This study is required to combine the information on the operating characteristics of the components of a capsule pipeline to determine the system capabilities. This should be done on a component basis as well as for the overall system so that new information can be readily introduced.

There are two types of operation which should be considered in this study - the first relating to single commodity transport where the scheduling requirement is necessitated by the capsule fabrication, injection and bypassing systems, and the second to multicommodity transportation (common carrier) where the capsule sensing function also enters into the determination and additional switching functions may be required. The estimates used here for common carrier scheduling assume the single commodity study is available.

Scope of Work:

Computer study - development of a model simulating the scheduling of the capsule pipeline which incorporates the operating characteristics of the pipeline components.

1. Single commodity.
2. Common carrier operation.

Personnel Required:	Period:
1. Single Commodity	
1 Professional	3 months
2. Common Carrier	
1 Professional	5 mon hs

Cost:	
1. Single Commodity	
Staff	$5,000
Overhead @ 250%	12,500
Materials & Supplies	2,500

Cost:

2. Common Carrier

Staff	$8,300
Overhead @ 250%	21,000
Materials & Supplies	2,500

LEAKAGE, BREAKAGE AND BLOCKAGE DETECTION AND TREATMENT

In any pipeline carrying capsules, there are potential problems due to leakage of carrier liquid from the pipeline, blockage of the pipeline with solid and breakup of capsules. This study is aimed at outlining methods of minimizing the system upset arising from such occurrences and at sensing the problem and alerting the operator early. The study will also include an outline of measures to locate leaks and blockages and to repair and remove broken capsules.

Scope of Work:

This involves evaluation of different possible systems for upset sensing and correction followed by tests in the prototype test facility to confirm their operation and establish operating limits.

Personnel Required:	Period:
1 Professional	8 months

Cost:

Staff	$13,000
Overhead @ 150%	19,500
Materials & Supplies	50,000
Test facility 3 months @ $6000/mo.	18,000

CHAPTER 3

Possible Development Program

3.0 Introduction

Chapters 1 and 2 outlined the additional work required to develop all facets of capsule pipelining to the point where they can be applied to an industrial scale installation. No attempt was made, however, to assign an order of importance to the different projects.

There is a variety of combinations of programs that could be followed in developing the capsule pipeline system to an industrial reality, differing in the capsule production and capsule recovery steps according to the commodity being considered and on the options chosen for injection, pump bypass and retrieval. It would be possible to study the complete spectrum of projects outlined in a program of concurrent projects without regard for the probable course or to tailor the path to fit any hypothesized scheme of development. Four sample development programs will be outlined in the succeeding pages. Three are directed to specific capsule types - compacted garbage capsules, cast sulfur capsules and filled rigid capsules and one to general capsule pipelining. In each of these programs the component projects have been taken from those outlined in Chapter 2 and combined to give a sample time schedule for the overall development according to the importance of the component projects in the development.

Component projects have been classified according to their significance or importance through use of priority levels. These priorities and the criteria used in classifying the projects are:

Priority I: Development of technology essential to the pipeline transport and not currently available.

Priority II: Development of technology essential to the pipeline transport which is an attainable extension of existing technology.

Priority III: Adaptation of existing technology to capsule pipeline use; or definition of system behavior required for economic evaluation.

Classification of projects according to these priority levels is, to some extent, subjective and in the examples presented below there are a number of projects which

could be given different priorities.

No attempt has been made to optimize the development programs and the schedules could possibly be adjusted by assigning more personnel to some of the projects in order to shorten the required time for completion. Interaction between projects has not been noted explicitly but should occur in some areas, as for example between capsule handling and commodity recovery studies, between abrasion resistance and coating studies, etc. In addition, at the present stage of development, detailed costs are not known with accuracy and it is not possible to differentiate between project costs for different systems (e.g. no differentiation can be made between vane bypass development costs for sulfur or rigid filled capsules or between coating development costs for garbage or sulfur capsules).

The programs outlined below for individual commodities would be preceded by an economic estimate based on the program outlined in Part II of this study. This preliminary evaluation would have established the economics of the proposal and the development program would then define the cost of the technology and economics to the extent required for detailed pipeline system design.

The fourth program indicates the way to proceed with the development of capsule pipelining in a general way without considering specific commodities at the outset. Evaluation of the system would be made as the study progresses and opportunities for commercial applications occur.

3.1 Program A - Garbage Transportation

The garbage transport system envisaged involves production of capsules of garbage by compression at an urban transfer center for shipment by pipeline to a landfill site or other disposal. As considered at present, it would require no intermediate pumping stations, since the distance is sufficiently short to handle with one pumping station at source. The garbage capsules would be recovered at the terminal and disposed of directly or after modification as landfill. A general description of the system is given in reference I-28, Chapter 1 and a schematic diagram is shown in Figure 15.

This system has some peculiar characteristics that require modification of the general component development schemes given in Chapter 2. These will be emphasized in the following discussion of the program.

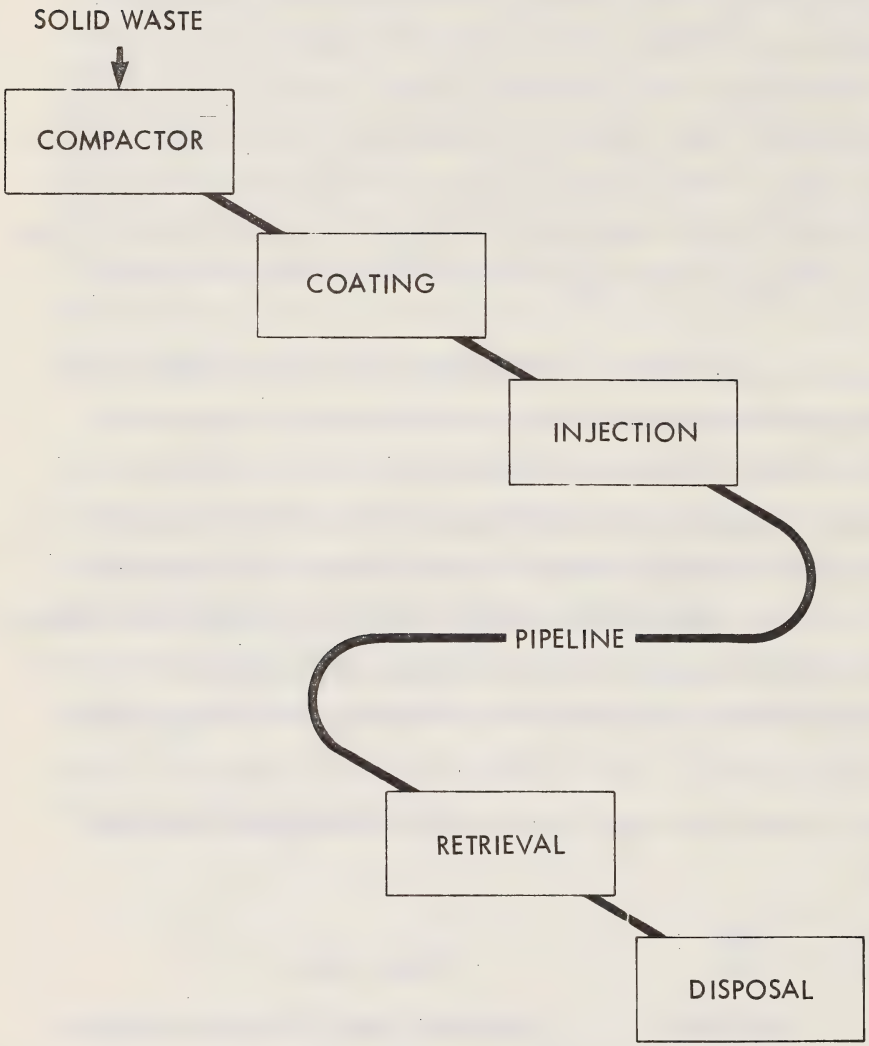
As noted in the general discussion of programs, three levels of priority have been recognized according to whether the component is: (I) Essential for operation of the pipeline system and not presently available; (II) essential for pipeline operation but an extension only of existing technology; (III) necessary for economic evaluation only or necessary for operation but within the capabilities of existing technology.

In terms of these distinctions, the priorities for development of garbage pipelining are:

Priority Level	Project No.	Project Name
I	A-III-1-a	Compressed Capsule Formation-Compactor
	A-IV-6	Coating of Capsules
II	A-IV-1	Required Capsule Strength
	C-4*	Rotary Valve Bypass Device
	C-12*	Leakage, Breakage and Blockage
III	A-IV-7	Liquid Retention
	A-IV-9*	Commodity Recovery
	C-7	Capsule Handling
	C-8	Interface.

* Project outline modified from Chapter 2.

Figure 15



GARBAGE PIPELINE SYSTEM

Considering these projects in detail as they relate to garbage transport, the first priority projects define the capsule fabrication techniques. Compressed capsules can be made by extrusion or straight compaction and here compaction seemed to be the preferred choice because of the experience with compactor baling in St. Paul (i.e. American Hoist & Derrick Co.). Extrusion technology is fairly advanced but does not seem as suited to the heterogeneous feed that would come from a garbage shredder. Coating is considered necessary in the case of garbage capsules because of the effects of surface attrition and carrier liquid contamination during contact of the capsule surface with the liquid. These two studies are considered essential before proceeding on the remainder of the development work - in brief, it must be possible to produce coherent capsules and minimize carrier liquid contamination.

In the second priority projects, consideration is given to the capsule strength when subjected to capsule interaction in trains, to the injection device and to procedures required to detect and eliminate operating problems. The study on Required Capsule Strength goes beyond the behavior of single capsules to capsule train testing to establish that capsule interaction does not disintegrate the capsules. Testing of model scale trains does not give as satisfactory a test of capsule integrity under operating conditions as could be obtained by instrumented capsule studies and development of quality control tests for capsule fabrication; however, it is less expensive and quicker and the instrumented capsule tests would be undertaken more to develop capsule pipeline technology than to design a single commodity pipeline.

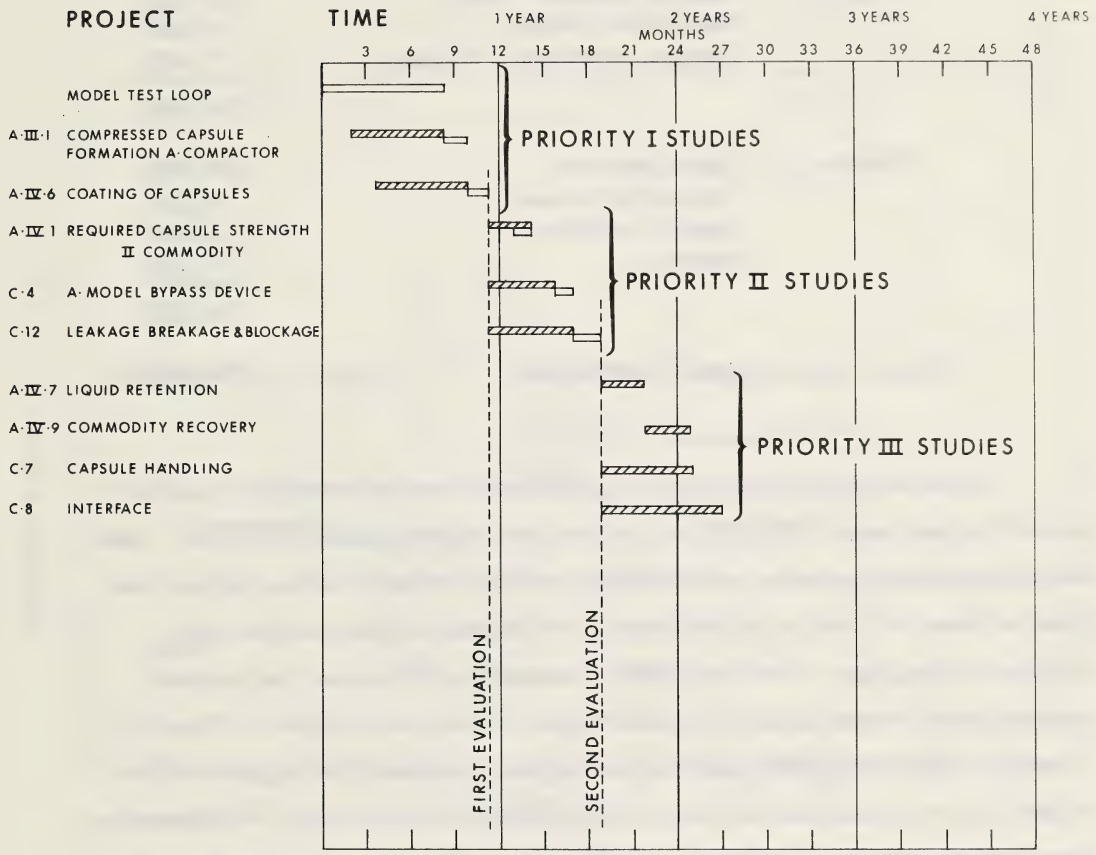
The development of the rotary valve device for use as an injector is a simpler problem than its development for a pump bypass because the capsules can be supplied to the rotary valve at a controlled rate. For this reason, the costs and time associated with this development have been scaled down from those outlined in Chapter 2. The other project considered as a second priority one is the detection and elimination of leakage, breakage and blockage. This has also been scaled down in magnitude from the outline of Chapter 2 due to the fact that the pipeline has only a source pumping station and the overall system is small and will operate at relatively low pressures.

In the garbage pipeline concept, third priority projects are the liquid retention which is important for landfill management; commodity recovery which in this case would consider possible modification of the capsule shape at the downstream terminus to get higher packing density as landfill (i.e. production of rectangular bales from the cylindrical capsules) and the two terminal studies on Capsule Handling and the interface at the delivery end of the pipeline. These latter two are well within the capability of today's technology and have been considered design and fabrication problems which could be presented immediately to an equipment manufacturer.

In the case of the garbage pipeline, the line is relatively short and the capsules will be close to neutral density so the methods of decreasing pressure gradient - capsule shape and surface effects - have little importance. Abrasion resistance is considered under capsule coating,and bonding should not be a problem with the rough surface presented by a compressed garbage capsule. The short length also reduces the importance of pipe investigations. As there are no bypasses foreseen in the pipeline, there is no need for diversion, velocity adjustment, deceleration or capsule sensing studies. The system is quite simple and very little control technology is required, so instrumentation software and detailed scheduling studies would not be required and the control aspect would be included in the other hardware studies - capsule fabrication and the rotary valve device.

The projected time schedule is shown in Figure 16 where the first priority projects, including test loop design and construction require 11 months, the second priority projects 8 months and the third priority projects a further 8 months, for a total development time of 27 months. Cost of the projected development program - including testing costs for the projects but excluding the capital cost of the test loop are:

Figure 16

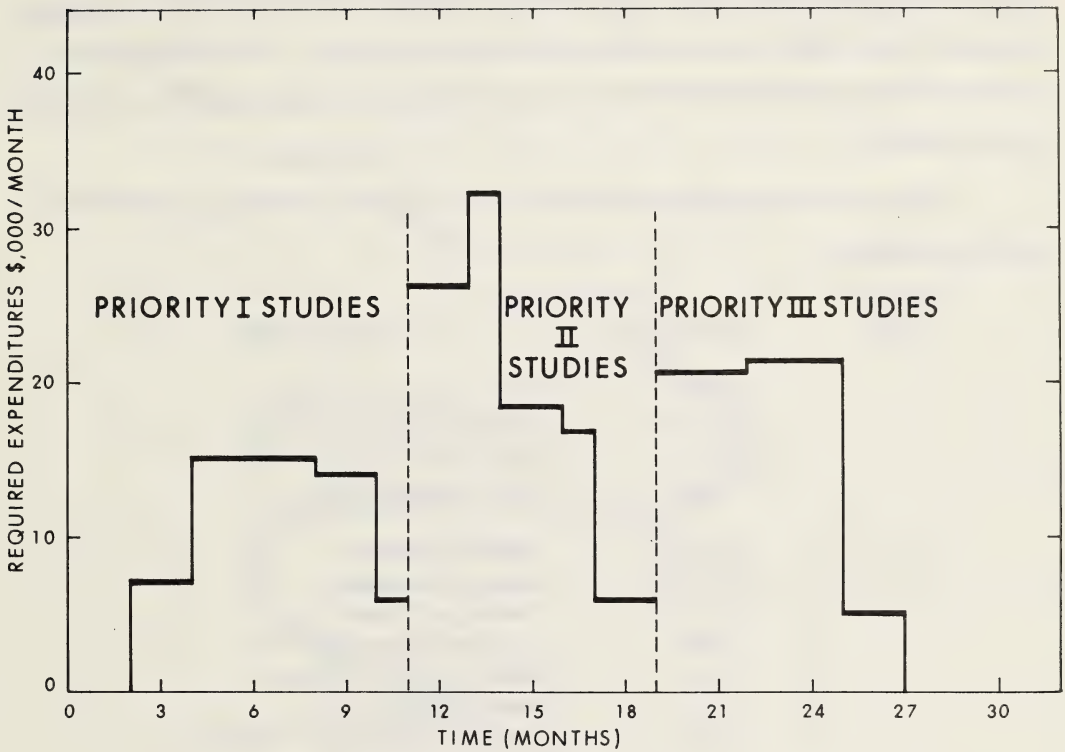


GARBAGE PIPELINE DEVELOPMENT PROGRAM

Priority I	Compressed Capsule Formation	$54,500
	Coating of Capsules	54,000
		$ 108,500
Priority II	Required Capsule Strength	$29,300
	Rotary Valve Device	44,200
	Leakage, Breakage & Blockage	76,400
		$ 149,900
Priority III	Liquid Retention	$14,000
	Commodity Recovery	16,000
	Capsule Handling	65,000
	Interface	41,000
		136,000
	Total Project Costs	$ 394,400

To the total project costs of $394,400 would have to be added the capital cost of the test loop - $155,000, to give the total program cost of $544,400. There are additional costs relating to test facility staff salaries and overhead during free time but these will not be included here on the assumption that the free time is utilized in other ways. The distribution of expenditure throughout the program, assuming that average project expenditure rates can be used, is shown in Figure 17. There are other criteria that could be used to plan the overall test program and one might be to try to maintain continuity of operation of the Test Loop. No attempt has been made to schedule more than one test program in the Loop at any one period and this possibility would certainly have to be considered.

Figure 17



EXPENDITURES - PROGRAM A - GARBAGE PIPELINE DEVELOPMENT

3.2 Program B - Sulfur Transportation

A schematic diagram of a sulfur pipeline system is shown in Figure 18. The development program outlined here for sulfur transport assumes that a preliminary evaluation such as that given in Part II has indicated the optimum density of capsule and its form (cylinder or sphere). The object of the suggested program would then be to define the system more satisfactorily so that the economics of potential installations can be predicted with better accuracy. If it was proposed to experimentally consider all potential transport methods, the study would be considerably more expensive.

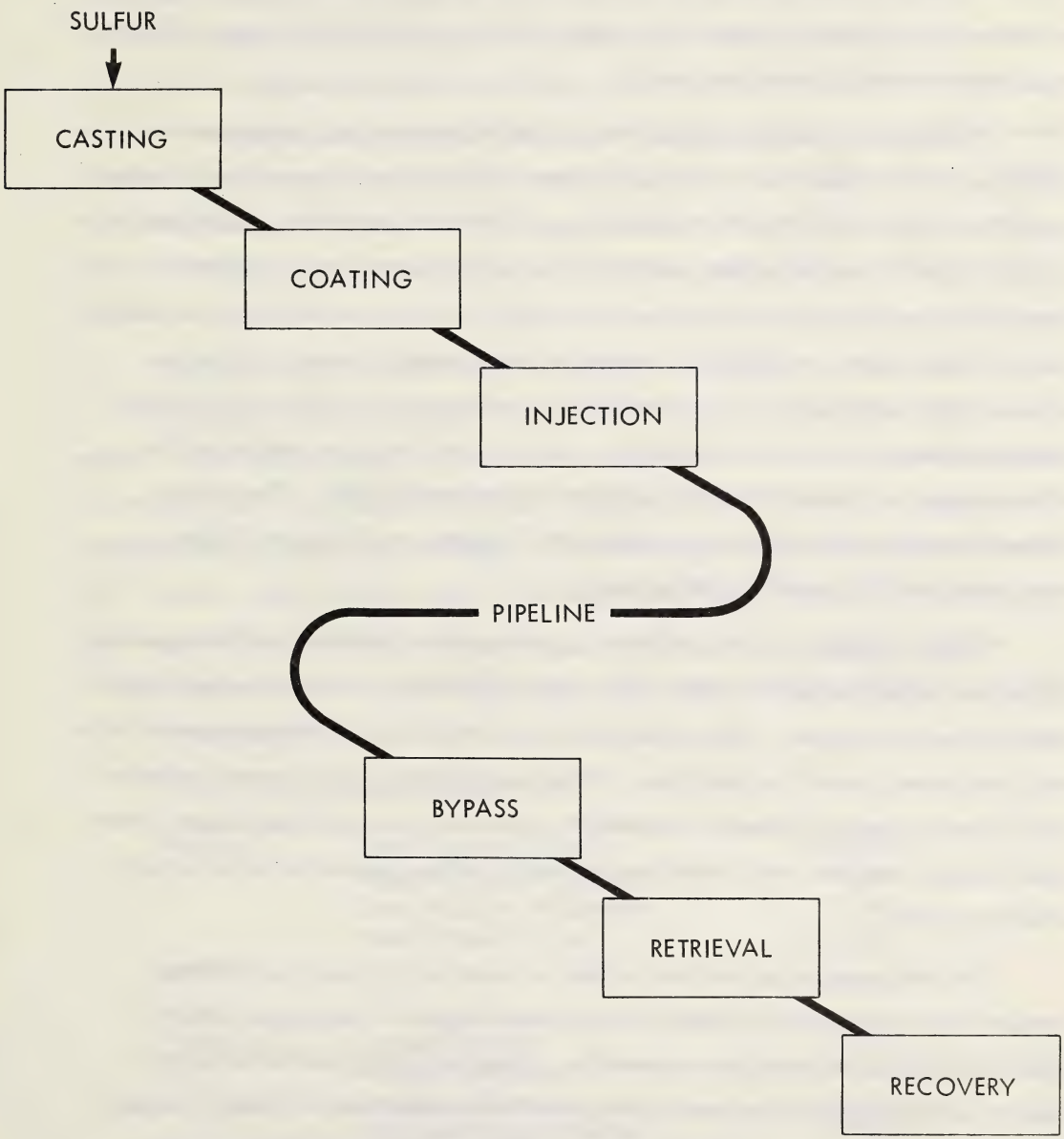
Based on the preceding definitions of priority levels, the list of priorities for sulfur pipelining is:

Priority Level	Project No.	Project Name
I	A-II-1	Cast Capsule Formation
	A-IV-1	Required Capsule Strength
	C-1	Train Velocity Adjustment
	C-4A	Model Bypass Device
II	A-IV-2	Capsule Strength
	A-IV-5	Abrasion Resistance
	A-IV-6	Coating of Capsules
	C-4B	Full Scale Bypass Device
	C-10	Instrumentation Software
	C-11	Detailed Scheduling
	C-12	Leakage, Breakage & Blockage
III	A-IV-7*	Liquid Retention
	A-IV-9	Commodity Recovery
	C-7	Capsule Handling
	C-8	Interface
	C-9*	Capsule Sensing

* Project outline modified from Chapter 2.

The first priority projects listed above consider the two main problem areas - cast capsule fabrication and pump bypass design. In this case the model test loop trials are simply the first scale-up for both capsule fabrication and the rotary valve

Figure 18



SULFUR PIPELINE SYSTEM

pump bypass device and should serve particularly to coordinate the train velocity adjustment with the rotary valve operation. The development of capsule fabrication techniques is considered the same in this study, whether solid spheres, foamed cylinders or cylinders containing voids are used.

If the bypass system development and capsule casting procedures appear satisfactory on the model line, the second priority projects can be commenced. These involve the construction of the full scale prototype of the bypass device, development of quality control tests for capsule strength, abrasion and coating tests which will determine the magnitude of attrition and determine if coating is necessary to decrease it or for other reasons, and finally, a number of system control projects. These are concerned with definition of the performance of components of the system such as the casting equipment, the rotary valve device used for injection and bypassing and the retrieval equipment to determine the operation of the overall system. The study on Leakage, Breakage and Blockage Detection and Treatment would include studies of coated capsules if the coating is to be used.

A sulfur pipeline would likely be a long installation and therefore the bypassing systems must accept capsules in random order and reintroduce them downstream of the pump at elevated pressures. This is likely the most critical step in the development and is considered in both test facilities. If the model prototype development indicated that the device could not operate satisfactorily, the change to a different bypass system would be made with the model scale loop and tested before proceeding to the second priority projects.

The third priority projects are the same as noted for Program A on Garbage Transport with the addition of Capsule Sensing tests required to develop a method of detecting capsules for proper system operation. Here both the Liquid Retention and Capsule Sensing projects have been scaled down from the outlines of Chapter 2 as only a single commodity or capsule type is to be considered. The Commodity Recovery project in this case would study the reprocessing options for the cast capsules and would have to consider a variety of possible end uses for the sulfur.

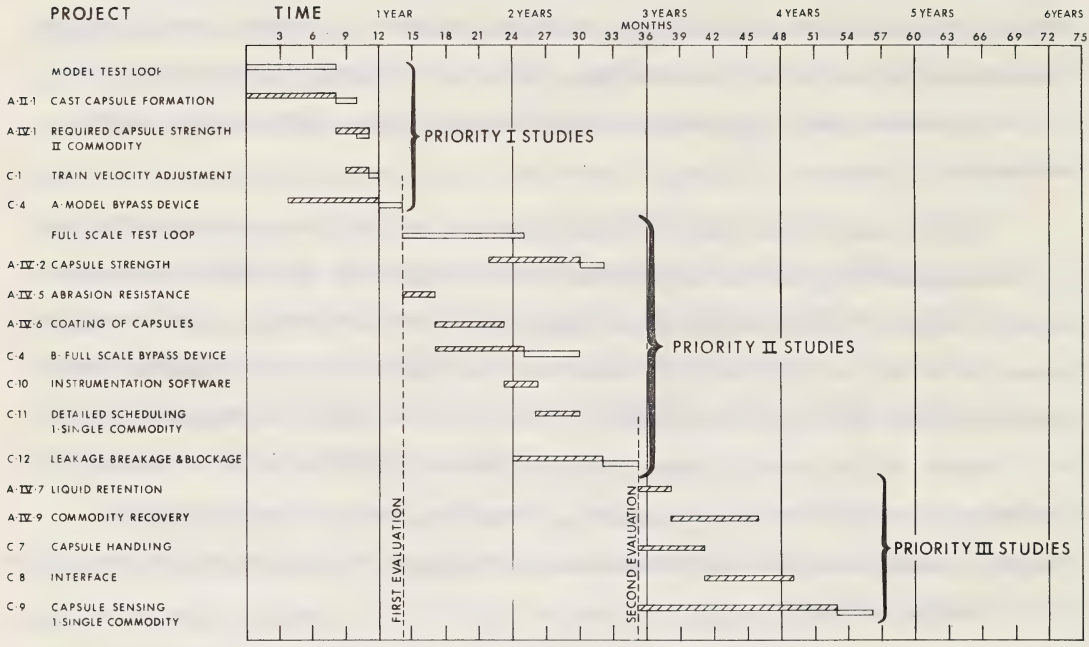
Capsule shape studies were not included here as it was felt that this would be an option considered with an operating line for improving performance because previous consideration has shown that the options would be either spherical capsules or cylindrical capsules with decreased density either through introduction of large voids or using foamed sulfur. Surface evaluation tests and the more detailed instrumented capsule tests for capsule strength would only be carried out as part of a broader capsule pipeline study devoted to a variety of commodities. Choosing to proceed with the rotary valve devices eliminates need for consideration of diverters, vortex pumps and deceleration mechanics.

On the basis of the priorities listed above and the project outlines from Chapter 2, a development program was prepared as shown in Figure 19. Here the first priority projects including the Model Scale Test Loop design and construction require 14 months, the second priority projects and Full Scale Test Loop need 21 months to complete and the third priority projects an additional 21 months to give a total development time of 56 months, slightly under 5 years. The most marked slack time period is caused by the design of the Full Scale Test Loop and, in practice, such a situation would be avoided by proceeding with the design phase of the larger test loop before the termination of all Priority I projects.

Costs of the individual projects are:

Priority I	Cast Capsule Formation	$107,000
	Required Capsule Strength	29,300
	Train Velocity Adjustment	31,600
	Model Bypass Device	77,000
		$ 244,900
Priority II	Capsule Strength	73,700
	Abrasion Resistance	17,000
	Coating of Capsules	54,000
	Full Scale Bypass Device	177,500
	Instrumentation Software	48,500
	Detailed Scheduling	20,000
	Leakage, Breakage & Blockage	100,500
		$ 491,200

Figure 19

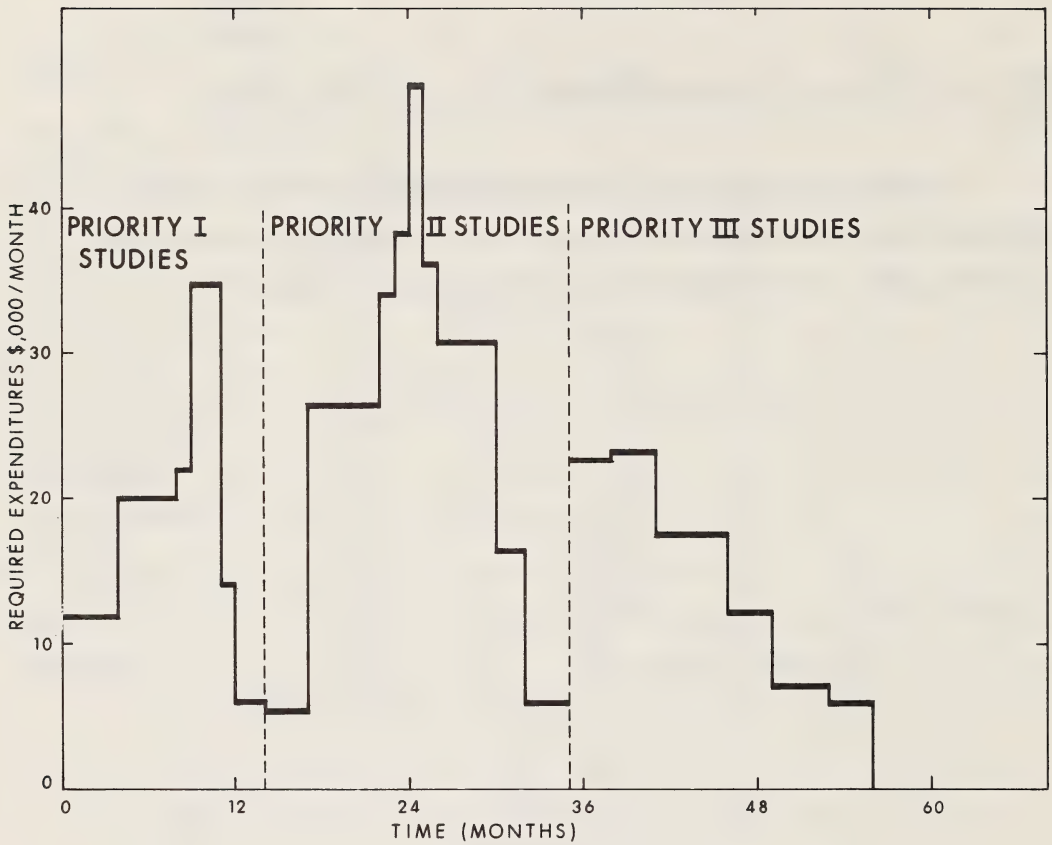


SULFUR PIPELINE DEVELOPMENT PROGRAM

Priority III	Liquid Retention	$14,000
	Commodity Recovery	42,000
	Capsule Handling	65,000
	Interface	41,000
	Capsule Sensing	48,500
		$ 210,500
	Total Project Costs	$ 946,600

The Model Test Loop would cost $150,000 and the Full Scale Test Loop $210,000 which must be added to the project costs to give the total program cost of $1,306,600. The distribution of expenditures is shown in Figure 20.

Figure 20



EXPENDITURES - PROGRAM B - SULFUR PIPELINE DEVELOPMENT

3.3 Program C - Rigid Filled Capsules

A schematic diagram of a filled capsule pipeline system is shown in Figure 21. In the case of filled capsules, a variety of materials could be used to make the containers. The program developed here assumes that preliminary assessment could narrow the choice down to one or two which could be compared during Priority I studies of utilization and capsule strength required to define the preferred type for further development work. As was the case with the sulfur capsule program, additional expenses will be involved if more capsule types are included for all the tests.

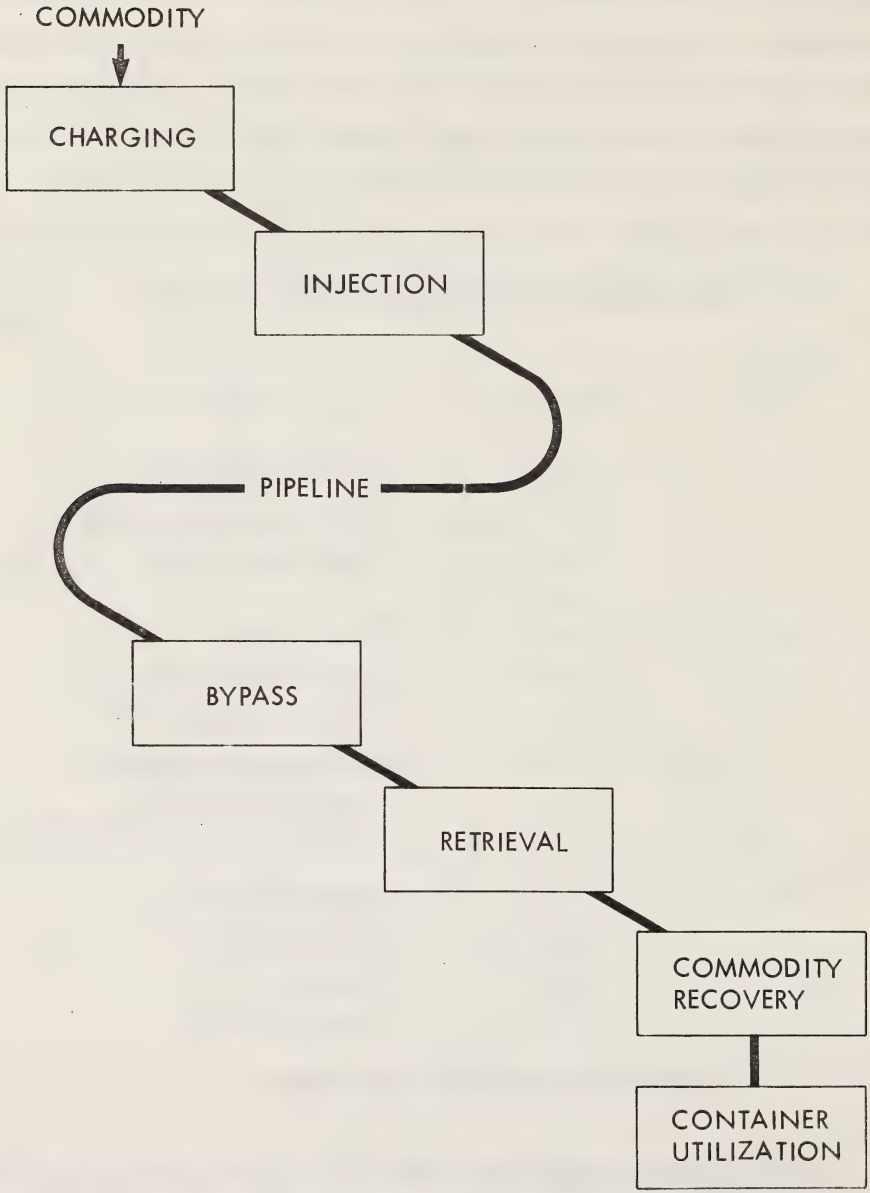
The list of priorities for filled capsule transport is:

Priority Level	Project No.	Project Name
I	A-I-1	Container Utilization
	A-IV-1	Required Capsule Strength
	C-1	Train Velocity Adjustment
	C-4	Model Bypass Device
II	A-I-2	Closure Design
	A-IV-9	Commodity Recovery
	C-4	Full Scale Bypass Device
	C-7	Capsule Handling
	C-10	Instrumentation Software
	C-11	Detailed Scheduling
	C-12	Leakage, Breakage & Blockage
III	A-IV-2	Capsule Strength
	A-IV-5	Abrasian Resistance
	A-IV-7*	Liquid Retention
	C-8	Interface
	C-9*	Capsule Sensing

* Project outline modified from Chapter 2.

The first priority projects listed above are concerned with container disposal at the delivery terminus (i.e. container utilization); with the required strength properties of the capsule and with the capsule bypass system at the model scale (i.e. the prototype for the 4 inch loop. The model prototype tests with the rotary valve pump bypass and the velocity adjustment devices are intended to yield the best designs for scale-up to the

Figure 21



FILLED CAPSULE PIPELINE SYSTEM

full-scale prototype which will be fabricated for testing in the 10 inch diameter pipeline loop in a subsequent project. If the designs generated on the model prototype loop appear satisfactory, work will commence on the second priority projects.

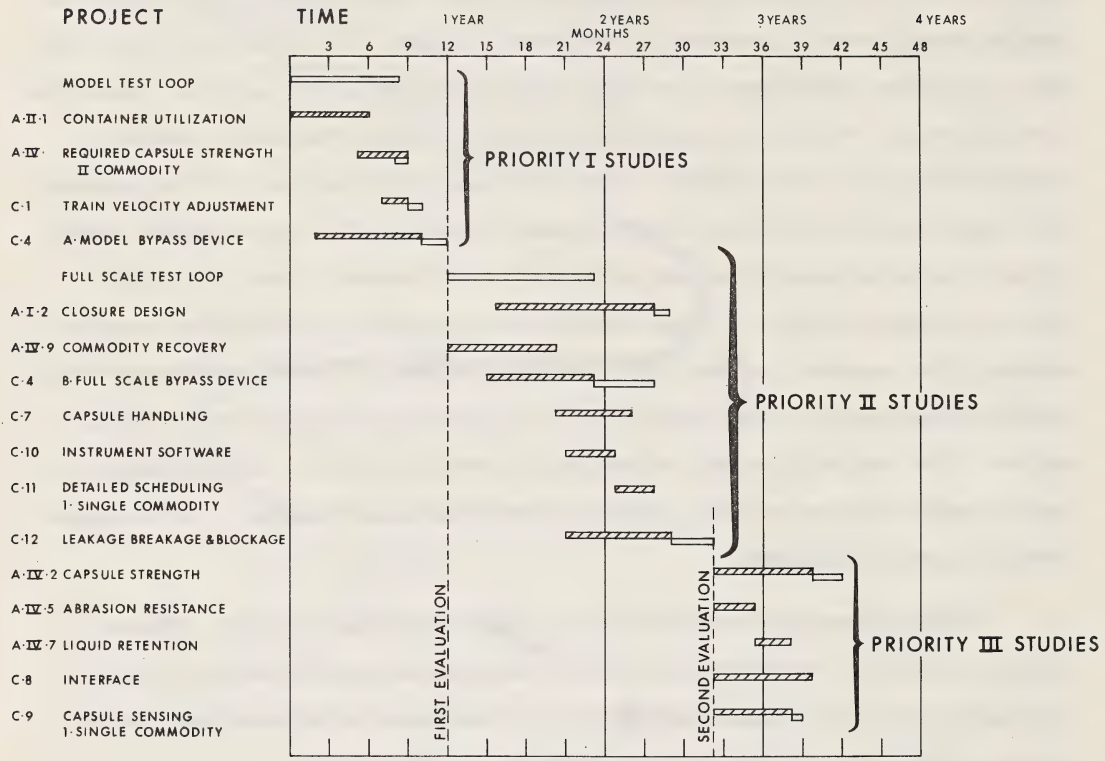
In the filled capsule tests, the container material properties will be much better defined than was the case with either garbage or sulfur capsules and the development of capsule strength tests is considered a third priority project. Of prime importance in the case of containers which have to enclose a cargo is the design of a container closure that is readily sealed, maintains a good liquid seal and withstands the physical abuse of capsule interaction in the pipeline. Commodity recovery in the case of filled capsules will require mechanical design of the equipment to retrieve the cargo from the capsule. This will not be as severe a problem as it would be with reusable capsules but does require an original solution. Capsule handling is included as a second priority project because of the complexity of the cargo charging equipment. The major differences from current technology are in the large size of the containers and the high rate of filling required. The remaining second priority projects are the same as for sulfur transport - the full scale prototype test loop, the two control studies and the project to investigate potential operating problems.

Priority III projects include three on capsule properties - strength, abrasion and liquid retention, as well as the delivery interface and capsule sensing. Here also the liquid retention and capsule sensing projects have been scaled down from the projections of Chapter 2 to account for the limited scope of the study.

Capsule shape, surface evaluation and pipe evaluation have been omitted at the stage of the present study, as they are likely to yield marginal improvement only. Coating studies were not necessary as the rigid container will effectively separate the cargo from the carrier liquid. As in Program B, the choice of the vane pump bypass eliminates the diverter studies, the vortex pump and capsule deceleration studies.

The development program derived from the above list of priorities and the project outlines of Chapter 2 is given in Figure 22. The Priority I projects require 12 months, including the Model Prototype Test Loop while the Full Scale Loop and the other

Figure 22



FILLED RIGID CAPSULE DEVELOPMENT PROGRAM

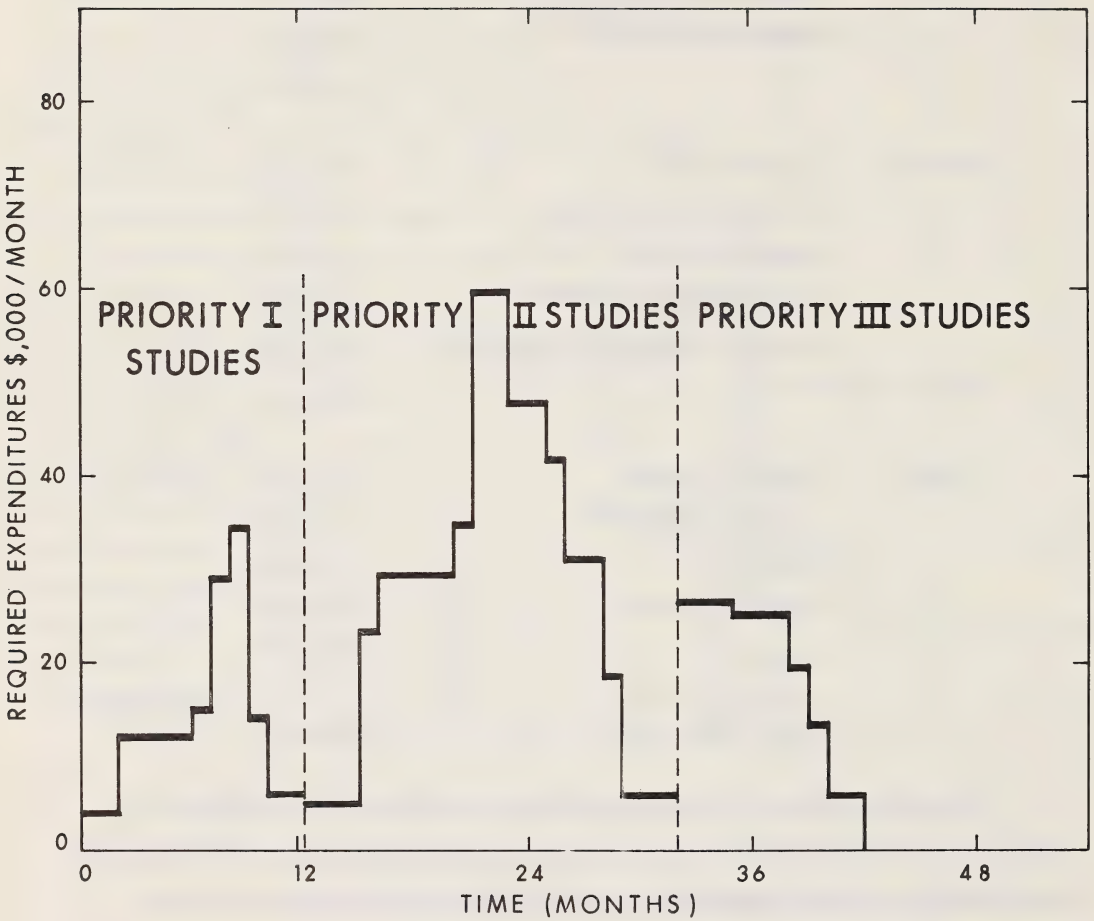
second priority projects require 20 months. Priority III projects require a further 10 months to give an overall program duration of 42 months - 3.5 years.

Costs of the proposed program on a project basis are:

Priority I	Container Utilization	$24,000
	Required Capsule Strength	29,300
	Train Velocity Adjustment	31,600
	Model Bypass Device	77,000
		$ 161,900
Priority II	Closure Design	$75,000
	Commodity Recovery	42,000
	Full Scale Bypass Device	177,500
	Capsule Handling	65,000
	Instrumentation Software	48,500
	Detailed Scheduling	20,000
	Leakage, Breakage & Blockage	100,500
		$ 528,500
Priority III	Capsule Strength	$67,700
	Abrasion Resistance	17,000
	Liquid Retention	14,000
	Interface	41,000
	Capsule Sensing	48,500
		$ 188,200
	Total Project Costs	$ 878,600

The model prototype test loop would cost an additional $150,000 and the full scale facility $210,000 which gives a total estimated investment of $1,238,600. The distribution of these expenditures over the period of the program is shown as Figure 23.

Figure 23



EXPENDITURES - PROGRAM C - RIGID FILLED CAPSULE DEVELOPMENT

3.4 Program D - Complete Capsule Pipeline System

The previous three examples have outlined possible development programs for specific types of capsules. If the preliminary economics were considered promising for a number of applications and a more general development of capsule pipeline technology was required, a slightly different approach would be followed which would place more emphasis on the mechanics of capsule behavior and characterization of capsules through measurable properties rather than simply testing representative capsules. It is also assumed that such a comprehensive study of capsule pipeline technology would consider the technologies currently judged to be of marginal technical merit such as the vortex pump. The following pages outline one possible program for this development.

The list of priorities for the projects of Chapter 2 in the context of a complete capsule pipeline system are:

Priority Level	Project No.	Project Name
I	A-I-1	Container Utilization
	A-II-1	Cast Capsule Formation
	A-III-1	Compressed Capsule Formation a. Compactor b. Extruder
	A-IV-1	Instrumented Capsule - Model Scale
	A-IV-9	Commodity Recovery
	C-1	Train Velocity Adjustment
	C-4	Model Bypass Device
II	A-I-2	Closure Design
	A-IV-1-B	Instrumented Full Scale Capsule
	A-IV-2	Capsule Strength
	A-IV-4	Surface Evaluation
	C-4	Full Scale Bypass Devices
	C-7	Capsule Handling
	C-9-1	Capsule Sensing - Single Commodity
	C-10	Instrumentation Software
	C-11	Detailed Scheduling
	C-12	Leakage, Breakage & Blockage

Priority Level	Project No.	Project Name
III	A-IV-3	Capsule Shape
	A-IV-5	Abrasion Resistance
	A-IV-6	Coating of Capsules
	A-IV-7*	Liquid Retention
	A-IV-8	Bonding of Coatings
	B-1	Pipe Evaluation
	C-2	Fluid Diverter
	C-3	Mechanical Diverter
	C-5	Vortex Pump
	C-6	Capsule Deceleration
	C-8	Interface
	C-9-2	Capsule Sensing - Common Carrier

* Project outline modified from Chapter 2.

The first priority projects are related to capsule formation and disposition at the delivery terminus and to the bypass development with the exception of the instrumented capsule study in which the model scale tests will help to develop the instrumented capsule for use in the full scale test loop. It should be noted that both the compactor and extruder are included for compressed capsule fabrication, which is due to the extruder application for paste slug manufacture but it is not likely to be useful for garbage. Development of the bypass device requires a means of adjusting train or capsule velocities to separate the capsules for rotary valve operation, so this has been included as a Priority I project. At the end of the Priority I program, methods of capsule fabrication should be known and prototype production units ready for the large test loop; the instrumented capsule study should have solved many of the problems of communication and detection and smoothed the way for sensing and recording pressure profiles and other capsule phenomena and the rotary valve pump bypass should have been perfected on the model prototype loop and the design be ready for scale up to full scale (i.e. 10 inch diameter).

In the second priority projects, surface evaluation has been included as a more general approach to characterizing capsule behavior. The first stage of the capsule sensing study, dealing with one commodity only is included as a Priority II project as it is a necessary prerequisite to the common carrier capsule sensing study where the possibility of differentiating between capsules and controlling their paths through the system is investigated.

The remainder of the projects have been included at the third priority level. These include those designed to optimize economics - capsule shape, abrasion resistance, etc., as well as the diverter studies and the capsule deceleration investigation for multiple barrel bypass systems, the vortex pump and interface projects. Development of capsule sensing for common carrier applications is also included as a Priority III project. The liquid retention project has been expanded slightly over that outlined in Chapter 2 and the laboratory and prototype phases of Projects C-2 and C-5 (fluid diverter and vortex pump) have been combined.

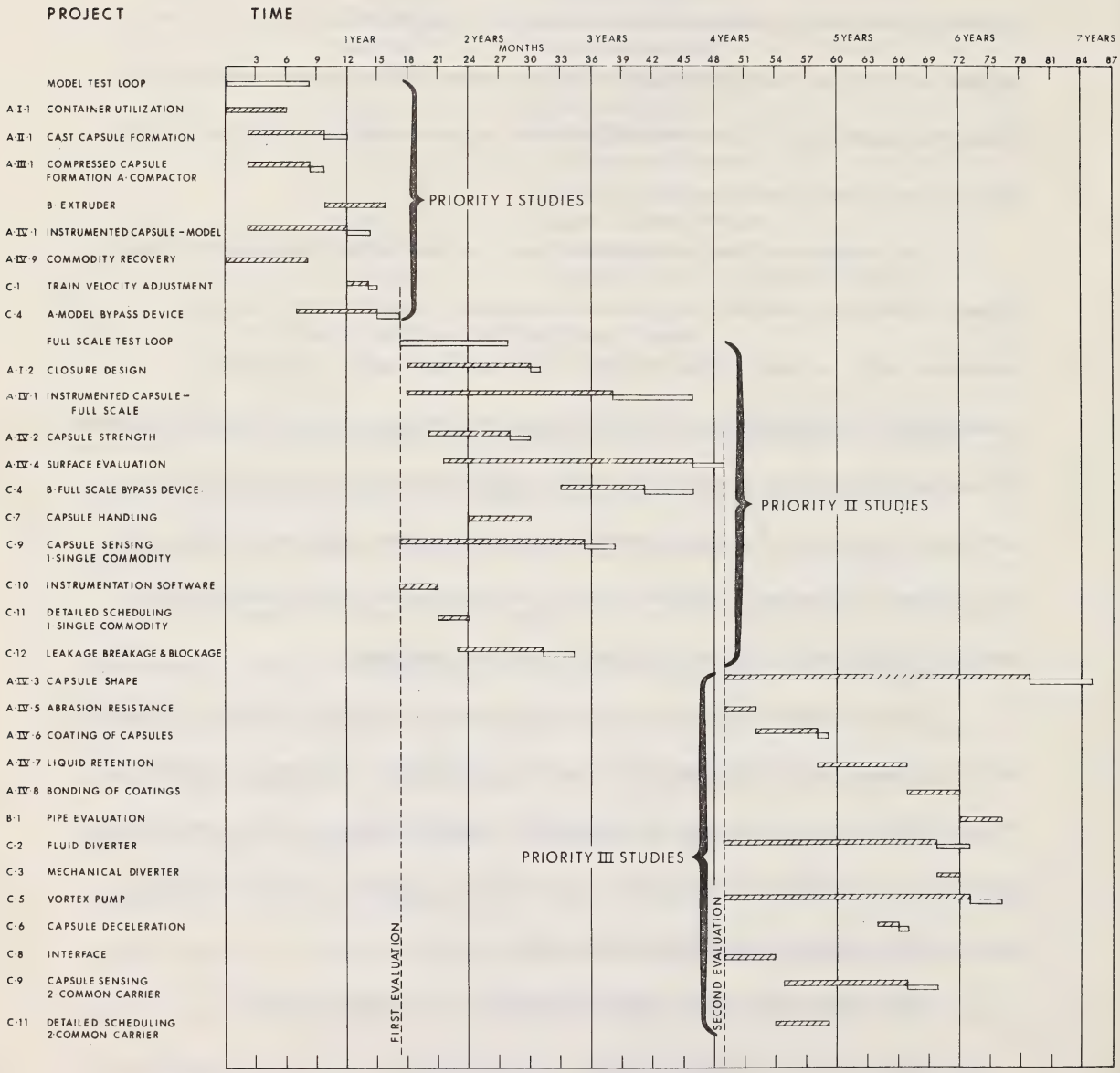
The development program based on these project priorities is given in Figure 24 which indicates time requirements of 17 months for Priority I projects, 32 months for Priority II projects and a further 36 months for Priority III projects. The overall time required for completion of the program is 85 months or slightly over seven years; however this could be appreciably reduced by

(a) Carrying our test programs concurrently in the test facility;

(b) Increasing personnel devoted to some projects;

(c) Diffusing some projects across evaluation decision points so that initial design work on a priority level can start prior to general completion of work at the previous priority level.

Figure 24



DEVELOPMENT PROGRAM - COMPLETE CAPSULE PIPELINE SYSTEM

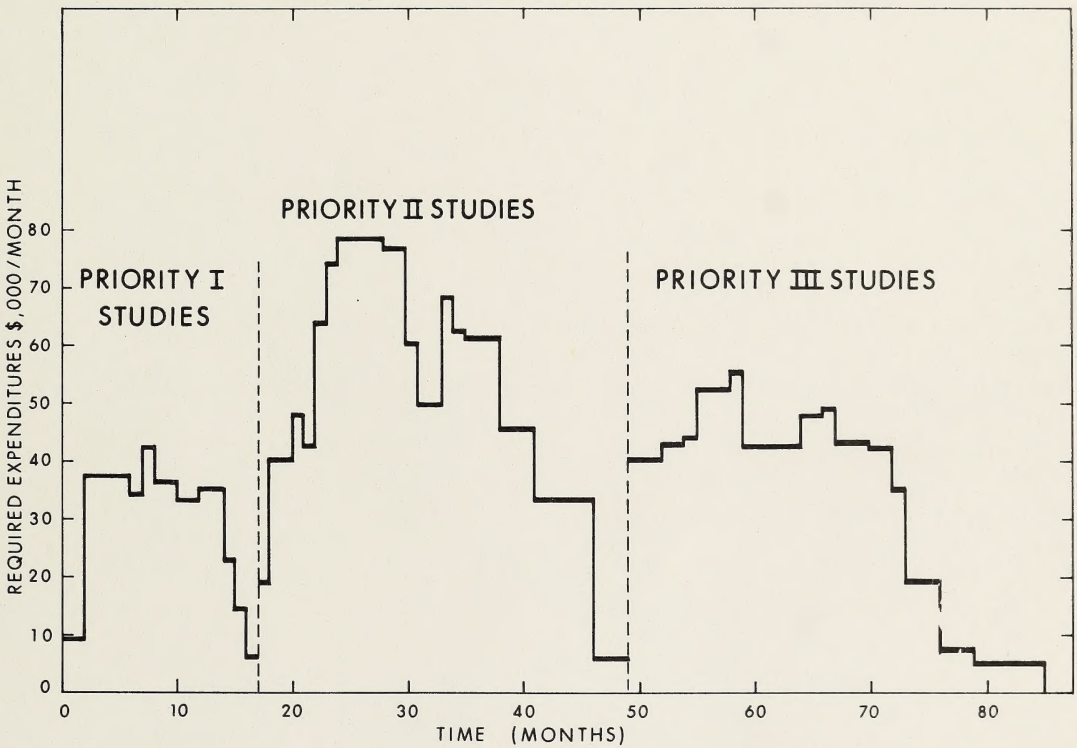
The estimated project costs for the program, based on the project outlines of Chapter 2 are:

Priority I	Container Utilization	$24,000
	Cast Capsule Formation	107,000
	Compressed Capsule Formation	
	a. Compactor	54,500
	b. Extruder	52,000
	Instrumented Capsule - Model Scale	115,800
	Commodity Recovery	42,000
	Train Velocity Adjustment	31,600
	Model Bypass Device	77,000
		$ 503,900
Priority II	Closure Design	$75,000
	Instrumented Capsule - Full Scale	355,700
	Capsule Strength	73,700
	Surface Evaluation	532,000
	Full Scale Bypass Device	177,500
	Capsule Handling	65,000
	Capsule Sensing - Single Commodity	145,000
	Instrumentation Software	48,500
	Detailed Scheduling - Single Commodity	20,000
	Leakage, Breakage & Blockage	100,500
		$ 1,592,900
Priority III	Capsule Shape	$ 262,000
	Abrasion Resistance	17,000
	Coating of Capsules	54,500
	Liquid Retention	42,000
	Bonding of Coatings	37,000
	Pipe Evaluation	23,000
	Fluid Diverter	146,000
	Mechanical Diverter	10,500
	Vortex Pump	400,000
	Capsule Deceleration	16,400
	Interface	41,000
	Capsule Sensing - Common Carrier	120,000
	Detailed Scheduling - Common Carrier	31,800
		$ 1,201,200
	Total Project Costs	$ 3,298,000

To these project costs must be added the cost of the model prototype test loop ($150,000) and the full scale prototype test loop ($210,000) to give a total program cost of $3,658,000. A graph showing the distribution of expenditures over the duration of the program is given in Figure 25.

For comparison, the concurrent development program would require 65 months if considered on the same basis as this sequential program of only limited overlapping of test programs in the test facility. This would increase the average monthly expenditure during the later stages of the program and would require more personnel. Considering Figure 24, it would involve simply overlapping Priority III projects into the Priority II period (i.e. there is only one month of unscheduled test facility time to the end of the Priority II period). This could doubtless be shortened still further by detailed consideration of the testing programs required and determination of which could be run concurrently or, alternatively, by operating the test facility for more than one shift per day.

Figure 25



EXPENDITURES - PROGRAM D - COMPLETE CAPSULE PIPELINE SYSTEM DEVELOPMENT